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GENERAL DESCRIPTION OF BRIDGEPORT HYDRAULIC COMPANY'S SYSTEM.

BY SAMUEL P. SENIOR.*

[*Read September 19, 1933.*]

Just a short block below our main office, near the heart of Bridgeport, is our construction office. There are located our truck and automobile garages, machine shop, blacksmith shop, meter department, and chemical laboratories. In the west end of the city we have quite a large dock and storage yard for pipe, where we can receive pipe from any one of the three large eastern foundries by water freight. We have no siding there, and because of that fact, and because rail freight is higher, we get very little pipe by rail except in an emergency. We get it by barge and unload it and store it in the ample yard at our disposal.

I shall not give a recitation of the Company's operations during its life of about eighty years, but I shall tell a little about the scope of our operations; not much about the details of operating. My associates will tell you some of those things in the papers that follow.

Our system runs from the Norwalk line along the Sound, up the Housatonic River to and including Shelton, a distance of about 27 miles. We supply the towns of Westport, Fairfield, Bridgeport, Stratford, and Shelton, and to a smaller extent some of the few interior towns.

Our system is entirely a gravity system except for a few booster stations, where we pump into elevated standpipes to take care of a limited number of people in different high districts. These booster stations all have centrifugal pumps actuated by motor drive, furnished by a small motor, as a rule about 25 h.p. In that way we supply about 100 families.

We have about 100 sq. miles of watershed, located to the northeast, north, and northwest of Bridgeport. Of this area about 70 sq. miles are developed. Our watershed is very rugged in character; it is sparsely settled and farmed. Since it is not a good farming community, about all the farming that is done is dairy farming. The average farmer has a very small amount of cultivatable land; the area is mostly pasture and woodland, scrub land. We are fortunate in that respect. We own outright about a quarter of this 100 sq. miles of watershed.

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We have no clay in this country, nor limestone. Hence the water coming down the small streams is comparatively clear and soft. We exercise supervision over the entire area. The reason we do this is that it is composed of small sheds; 30 sq. miles is about the extent of the largest. We learn about everything that is going on on these sheds. Our overseers who live in the different sections know about the conditions and avoid any trouble. Then, too, we have splendid laws in this state which enable us to clear up troubles. Thus it is unlawful for anybody to bathe in any water supply, or in any tributary of the supply. The officials of the State Department of Health coöperate with us splendidly in helping us to clear up nuisances. One of our statutes says that one may not put anything into a stream which will tend to pollute it, nor may one place polluting material where it may run into the stream. Because of this it is not very difficult to take care of the average situation, although we have had to buy a great deal of property when it was too difficult for the owners to clear up unsatisfactory conditions or for us to have them cleared up.

Our total storage capacity is about twelve billion gallons, contained in three different reservoirs. These reservoirs are connected directly into Bridgeport and are used not only as storage reservoirs but as distributing reservoirs. This is possible because they are not ordinarily drawn down more than a few feet during the dry season.

From west to east the three reservoirs are the Hemlocks Reservoir, which has a capacity of about four billion gallons, and which is at an elevation of 225 ft. above mean high water; next toward the east, the Easton Reservoir, with a capacity of about six billion gallons at an elevation of 300 ft.; and most easterly, the Trap Falls Reservoir, with a storage of about two billion gallons at an elevation of 312 ft.

We depend for purification on storage in these reservoirs, and on treatment at the dams where the water receives first in the gate chamber anhydrous ammonia, and below that in a gatehouse chlorine. Below each dam, too, is a house containing a Venturi master meter. Bridgeport is essentially a factory city, and the amount of water required depends largely on how the factories are running. We have averaged for a year, 34 m.g.d.; we have been down as low as 22 m.g.d., and at present we supply about 27 m.g.d. The increase from the low has been quite rapid since June. The reservoirs are interconnected, and there are regulating valves on the system.

It may be of interest to state how our construction work is taken care of. We do all of our own building,— pipe lines, canals, dams, bridges, and all related structures. They are built by our own force. For this purpose we maintained for a great many years the nucleus of a construction organization, including an engineer, resident engineer, master mechanic, foreman carpenter and foreman rigger. We have not employed a permanent general superintendent, who is a very expensive man ordinarily — the kind we employ — but we have hired such a man as the occasion would

require. We have quite a large construction plant. Such machinery as does not deteriorate we maintain. After we finish a job we sell a good deal of equipment that is not likely to be employed enough. When we are ready to start a job we quickly recruit the personnel of our organization, through contracting firms, our idea being to approach the performance of a contractor just as nearly as may be. Our work is pushed just as hard, particularly by the general superintendent, as any contractor's work, and it goes along very fast and the work is done cheaply. At the same time we have absolute control over the job at any moment. We can add any number of extras and do any work of that kind we want, and of course there is no reason in the world why the best materials should not always be used. For instance, we may be working at the bottom of a section of a dam when we think it might be of benefit to sink some holes and grout them. There is no hesitation about doing it. If the work were under contract we should have to make some kind of an arrangement with the contractor for an extra. We believe we get very good work and that we save about 20 per cent. of the cost of the structure. All of our men have had experience with contractors. They have been taken from the contracting organizations. Our general superintendent, who is the spark plug of the whole outfit, is taken from a contractor who has built large dams for New York City or other places and had experience on a number of similar jobs.

For a great many years we have been interested in forestry operations. Near our Hemlocks Reservoir, is located our nursery, where we raise about 150 000 seedlings a year. We not only raise standard varieties of trees but are raising a good many ornamental trees. This, through selling them at a profit, has enabled us to extend our operations. We do not expect to extend our foresting operations. Our nursery was quite a thriving and prosperous business up to the time of the depression. During the last year or two our sales have dropped. They have reached as high as $30 000 a year, and included mostly standard trees which are used for ornamental purposes in parks and on large estates.

We have planted some orchards, some of which are now about fifteen years old. Near one of the largest units is a cold storage plant, where we store peaches and apples. We usually put them in the storehouse in bushel crates after they have been graded as to size and weight. Our sales are wholesale, mostly. When we sell fruit we examine it and repack it in bushel baskets. We have found that they do better in the storehouse when they are packed in crates.

METHODS OF OPERATION OF THE BRIDGEPORT WATER DISTRIBUTION SYSTEM.

BY D. H. HALL.*

[*Read September 19, 1933.*]

The Distribution System of a public water supply, not including the large transmission mains from the reservoirs, though of vital importance, frequently receives too little consideration. Unless definite plans are formulated and carried out in the development of a distribution system, it will sooner or later become inefficient. Year after year, extensions are made here and there to provide for new developments both large and small with no ultimate plan in view. This must eventually result in a conglomerate mass of pipe lines of various sizes that fail to fulfill their intended purpose.

Over twenty years ago, we were confronted with this condition in Bridgeport. The distribution system had gradually grown to such an extent over a period of years that the proper pipe-line capacity did not exist in the proper locations, with the result that the supply in many of the older sections had been sacrificed by lack of foresight and there was insufficient supply for many of the new added areas.

To cope with this problem, maps were prepared showing the old system. On the same map, a proposed new revised system was plotted in a different color. As the proposed work progressed, the new installations were given a third color on the same maps. By adopting and following this method year after year, one could readily see at any time just how much of the old system remained, how much had been revised and how much remained to be completed.

The general plan adopted in designing the new system consisted of dividing the entire supply area into small sections, each section being bounded by adequate secondary feeders and gridironed with 8-in. pipe, this size being adopted as our minimum. Of course, much study and consideration were given to present and estimated future requirements in all districts and to an adequate arterial system to supply the secondary feeders. A complete fulfillment of this revised and improved system required many years of work and included a complete Pitometer survey of the entire system, the cleaning of 62 miles of mains of various sizes, the replacing of many miles of 4-in. by 8-in. pipe, in addition to extensive installations of larger sizes for arterial and secondary feeders.

It became apparent to us from a standpoint of efficiency and economy that installation of all new pipe lines in the distribution system should be made with a definite ultimate plan in view. If, for instance, an extension

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is required to supply a few houses where an 8-in. pipe is of sufficient capacity for present needs but the ultimate plan in that section provides for a 12-in. secondary feeder, the 12-in. pipe should be laid rather than the 8-in. By following such a scheme, all new installations are gradually and constantly working out a prearranged perfected plan.

Our present distribution system consists of about 400 miles of pipe of various sizes. The general specifications under which we operate provide for the use of Class B, American Water Works Specifications, cast-iron bell-and-spigot pipe, all of which is privately inspected and tested at the foundry, and is laid with at least 3½ ft. of covering. Globe-type cast-iron fittings are used exclusively, except where a tapping sleeve is necessary. Crane valves have been our standard for many years and are liberally placed throughout the system. Joint compound in place of lead for joints was adopted many years ago and both Leadite and Lead-Hydro-Tite have given very satisfactory results and are considered preferable to lead joints.

The flushing of mains is a major item of importance in our operation. This practice is carried on systematically throughout the year, though not so extensively during the winter months. After the transmission mains from the reservoirs have been thoroughly flushed in the spring, several crews are employed to continue on through the entire system. Each crew has its own section, and methods of procedure are carefully planned in advance. Other crews are constantly flushing dead ends, especially during the summer season. As some locations demand more attention than others, a complete record and schedule are maintained of all dead ends and show the required frequency of flushing in each particular case.

Our gate valves are inspected annually, and an accurate record is kept in cloth print,— loose leaf books which are corrected once a year. A copy is provided for every employee who may have occasion to operate valves during the process of his particular work.

The supply to the distribution system is from three sources by means of transmission mains varying in size from 48 to 30 in., all of which are interconnected through the distribution system.

On account of the different elevations of the reservoirs and the excess pressure, all these transmission mains are throttled and regulated with Ross regulating valves to maintain a constant pressure of about 80 lb. per sq. in. in the center of the city. By means of these valves, the supply from each reservoir at a different elevation is properly regulated according to the reservoir capacity, and a constant given pressure is maintained twenty-four hours a day. This method of regulating pressure has produced most gratifying results and benefits in many ways. From the insurance standpoint, which is very important, no objection is made to this manner of throttling a main supply. The effect on the distribution system is that breaks and leaks in mains and service pipes are greatly diminished. Waste through house leaks is unquestionably minimized on account of the fact

that the pressure does not increase at night as the consumption decreases. In case of fire or for any other reason when an increase in volume is demanded, the regulating valves automatically supply the requirement. Since these installations were made, major breaks in the mains at night have been practically eliminated, due, of course, to the slight fluctuation in pressure experienced.

It is with considerable satisfaction that we read the criticisms and recommendations of the National Board of Fire Underwriters in their original report of Bridgeport in 1904 in comparison with their latest report of 1931. The first report stated that the distribution mains were of insufficient diameter to give good protection, the majority being 6 in. or less in diameter. The pressure in the congested district was only 25 lb. per sq. in. and was required to be materially increased by rearranging the supply and distribution systems. The wide fluctuation in pressure dependent upon the rate of consumption and methods of distribution was criticized. Several columns were devoted to specific recommendations which reflected upon the inefficiency of the distribution system. The report of 1931, on the other hand, says that the water supply is adequate and reliable; the pressure is satisfactory; the distribution system is of large capacity; arteries and secondary feeders are well arranged. This report makes no recommendations or criticisms of the water supply. We naturally feel that we have made progress.

Our distribution system supplies about 25 m.g.d. to 33 000 services, 33 per cent. of which are metered. The service pipes consist of wrought iron, lead, brass and copper tubing; the specifications of the Public Utilities Commission allow the use of all these varieties. In the last few years a large percentage of services installed have been copper tubing. Meters are set by and at the Company's expense unless some are placed outside the building, in which case the customer must pay for a suitable protecting pit, according to the Public Utilities ruling. The statement that 33 per cent. of the services are metered is somewhat misleading on account of the fact that some of the suburban districts, such as Westport and the special high-service sections are almost 100 per cent. metered. In the city area of Bridgeport comparatively few meters exist on domestic supplies, but all industrial services are metered. Because so large a number of domestic consumers are on a flat rate basis, a systematic and continuous inspection is maintained of all premises. This inspection is for the purpose of checking and tabulating all fixtures and fixture leaks and testing for service-pipe leaks. Our policy is to furnish customers with an unlimited amount of water provided it is used legitimately and not wasted. This plan of inspection accomplishes its purpose and minimizes to a great extent the necessity of metering.

STEPS IN THE PURIFICATION OF THE BRIDGEPORT WATER SUPPLY.

BY FRANK C. BARROWS.*

[*Read September 19, 1933.*]

Very briefly I will try to outline the various steps taken by the Bridgeport Hydraulic Company to safeguard the supplies that deliver water to Bridgeport, Shelton, Stratford, Fairfield, Southport and Westport.

In 1911, at the Beardsley Park Pumping Station, we installed hypochlorite of lime equipment. This consisted of two large tanks fitted with agitators propelled by water motor. The hypochlorite was mixed thoroughly during the eight or ten hours daily that the pumps were in use and then allowed to settle. On the following morning the clear solution was drawn off, titrated, the proper dose for disinfection computed and the orifice set for delivery of solution into the suction well of the pump. This supply was used during the summer months only, being pumped directly into the main, the overload being taken care of by backing up into Charcoal Pond, a small distributing reservoir of 12 m.g. capacity which accommodated the night draft.

The next year, 1912, due to construction work started on the present Hemlocks Reservoir, it was necessary to make provision to protect Samp Mortar Reservoir as Cricker Brook, a tributary to Mill River, took all the drainage from the shed under development. The hypochlorite treatment at Samp Mortar was very similar to that employed at Beardsley Park except that its use was extended to three or four days a week for the entire year. From this supply the water was pumped into Osborne Hill Reservoir which was of concrete construction, having a capacity of 5 m.g. and giving ample storage for the needs of Fairfield and Southport at that time.

In 1916, the preliminary work was started on the present Easton Lake, on the site of the original Easton No. 1 and No. 2 reservoirs. Reservoir No. 1 was the distributing reservoir and No. 2 was a storage reservoir for keeping a constant level in Reservoir No. 1. This installation gave us our first experience with using chlorine gas and a factory-made chlorinator.

The machine was installed in the gatehouse on top of the dam. The chlorine gas applied through a silver tube and a saucer diffuser which was lowered into the gate chamber on the downstream side of the screens and as near the outlet as possible. This outfit worked very nicely except in extremely cold weather. Later, the same equipment was properly housed over the pipe line and application of chlorine gas was made directly into the main.

Due to the World War, construction work on Easton Lake was stopped

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and not resumed until 1923. The present dam was completed in 1926. In line with precautions taken all over the country, upon the entry of the United States into the World War, the Bridgeport Hydraulic Company installed chlorinators on all supplies in the early Spring of 1918. These consisted of two automatic, Venturi-operated chlorinators, one Pitot-operated chlorinator and two manually controlled chlorinators, all of the dry-feed type.

The results obtained from these installations were all that could be expected taking into consideration the extreme cold experienced during several winters, also the temperature of the water and the pressures under which gas had to be injected.

We continued the use of dry-feed machines for several years and on completion of Easton Lake installed a vacuum type solution-feed machine operated with hydraulic booster pumps, which proved very satisfactory. In 1928, we duplicated the layout at Hemlocks Reservoir, and in 1929, we installed the third machine at Trap Falls Reservoir.

With the increased size and elevation of the three main reservoirs, we have eliminated several of the smaller ones, thus making supervision and sanitation on the watershed much easier as well as consolidating the equipment for disinfection.

During 1932 we used ammonia in conjunction with chlorine on the Hemlocks system to overcome slight taste and odor. We also hoped to improve the condition on long runs with slight draft and numerous dead ends. Ammonia treatment resulted in a marked betterment of conditions as evinced by the decreasing number of complaints received and the reduced necessity of frequent flushing of dead ends. In 1933, we installed two additional ammoniators on the Easton and Trap Falls systems, where similar improvements were soon noted for which some credit must be given to ammoniation and due credit also to the fact that the year 1933, thus far, has been noted for a decided decrease of algæ growths in our reservoirs.

In 1932, we found it necessary to use 21 200 lb. of copper sulphate, whereas up to the present in 1933, we have used only 12 600 lb. Starting years ago with the use of 800 lb. of hypochlorite of lime for the purpose of disinfection, we have expanded and extended the process of disinfection until at the present time, we use approximately 30 000 lb. of chlorine gas and 5 400 lb. of anhydrous ammonia annually.

Our three reservoirs, Hemlocks, Easton Lake and Trap Falls, have a total storage of slightly over 12 billion gallons. This assures a very long detention period, giving time for extended sedimentation to greatly improve the physical properties of the water.

Frequent tests are made of the quality of the three supplies entering the city. Samples are collected on the outskirts to insure true samples rather than composite ones, thus giving results reflecting better the actual condition of each reservoir. Raw samples are taken directly from the reservoirs for both bacteriological and microscopical examination. Bacterial

results give a chance for determining the efficiency of disinfection and microscopical results often indicate the necessity for copper sulphate treatment. This is carried out in the usual manner long in practice. We use two or three boats with outboard motors in order to cover the greatest possible area in the least possible time. Good results are noticeable in 48 to 72 hours.

As to the problems that we have encountered in connection with the disinfecting of the various supplies, we firmly believe that proper housing with adequate heat throughout the winter months is essential for the proper functioning of all equipment. Plenty of room is necessary for the storage of cylinders.

For years we have used approximately 3.5 lb. of chlorine gas per million gallons, often increasing the dosage in the early spring or after a severe rain storm. The results of the ortho-tolidine tests made at a tap located approximately 300 ft. from the point of application have varied from 0.1 to 0.2 p.p.m. of residual chlorine.

Since the addition of anhydrous ammonia for the formation of chloramines, the ortho-tolidine tests have been carried out at greater distances along the lines of distribution, and results have been obtained as far as four miles from the point of application. In one supply it has been found necessary to reduce the amount of anhydrous ammonia used as an extremely high residual was obtained and chlorinous tastes developed in the outlying residential section.

A constant inspection of watersheds, occasional application of copper sulphate, and continuous chlorination augmented by ammoniation during the summer months gives the people of Bridgeport and surrounding towns a safe and potable water. This shows the attempt we have made to supply the public with water that conforms to public health requirements.

It is gratifying to the Bridgeport Hydraulic Company to note* that Bridgeport is on the honor roll of 14 cities with a population of 100 000 or over without a typhoid death in the year 1932.

Discussion.

Harry U. Fuller.† I would like to ask whether I understand correctly that at a point shortly below the point of the application of the chlorine a practically sterile water is obtained and that later on, in the system or in the grid iron, bacteria are found.

Mr. Barrows. The samples taken in the city will give us a bacteria count; but this year it is practically no higher than that in the outskirts. We have extended the process of disinfection into the lateral mains to a large extent.

E. Sherman Chase.‡ I would like to ask Mr. Barrows the types of

* Jour. *A. W. W. A.*, August, 1933. † Portland, Me. ‡ Boston, Mass.

growth and the times of the year in which he has experienced trouble in his reservoirs.

MR. BARROWS. The blue-green algæ have given us more trouble than anything else. There have been growths of *Asterionella* in one system. I think I can safely say that the latter part of May and June, over a period of twenty years, has been our heaviest season for growth.

MR. CHASE. Have you had any trouble in the winter?

MR. BARROWS. We had trouble one winter, yes, but we did not try to overcome it. We had about 14 in. of ice that winter. It was the same winter that New York City experienced trouble from *Synura*, but our trouble was with *diatoms*.

SAMUEL J. KYLE.* With reference to the use of copper sulphate, I would like to ask the dose, and whether copper sulphate is employed more than once a season.

MR. BARROWS. We use copper sulphate as often as we feel it is necessary. The average dose is about 1 lb. per m.g., sometimes 1½ lb. In some cases we have only considered the upper 20 ft. of capacity in determining the amount of water to be treated.

* Ansonia, Conn.

WATERSHED AND FORESTATION WORK OF THE BRIDGEPORT HYDRAULIC COMPANY.

BY WILLIAM C. POLLITT.*

[*Read September 19, 1933.*]

The use to which land acquired on watersheds can be put presents a problem to all water-supply systems which draw their water from surface streams. While some sections remote from streams may be rented for various purposes, by far the greater area is unsuitable for this purpose, because the land was acquired to eliminate properties which were nuisances or likely to become so. With this situation, most authorities turn to forestation and the Bridgeport Hydraulic Company is not different from others in that repsect.

Since the reforested area is but a small proportion of the watersheds, we doubt if we shall get any benefit from the trees in preventing soil erosion, or in preventing rapid run-off, but we have had two definite favorable results. One is the reaction of the water consumer to the sight of trees green throughout the year on the edge of the reservoirs and on adjacent lands. It seems to him and to us a proper setting for a public water-supply. The other definite result so far has been a monetary one. About ten years ago inquiries began to reach us from landscape architects and nurserymen as to whether we could sell some trees which were then about four to six feet high. These approaches led to business which increased each year; and it was but a short time before the receipts from these sales were more than sufficient to defray the costs of reforestation work and permitted us to go ahead on a larger scale also. The removal of these trees does not destroy the utility of the project as a prospective forest, as only the specimens most suitable for decoration are taken, the balance remaining to continue their growth to maturity. This money enabled us also to start a small nursery for more ornamental evergreen plants, which of itself produced some additional income, and the tract by this time has grown into an area of 24 acres of closely planted specimens, many of which will go on the market this coming spring.

Beginning in 1907 with a few thousand trees, we have planted consistently until today we have about 1 700 000 trees set out on watersheds of various reservoirs. Out planting schedule for the past five years has been 100 000 to 150 000 trees per year and in about three years more, all suitable areas will have been covered unless in the meantime more land is acquired.

In forest plantings, we prefer trees that have been two years in the seed bed and two years in the transplant bed. Younger trees than this

* Engineer, Bridgeport Hydraulic Co., Bridgeport, Conn.

have poorly developed root systems and have not attained sufficient height to combat the weeds and grass with which they will have to fight for existence; larger trees than this are too expensive to handle.

The choice of varieties for forestation purposes has given us some trouble, particularly in recent years, as it seems that in this period diseases and insect pests have multiplied. Our first planting in 1907 was of white pine 6 by 6 ft. apart, and this variety was continued for a few years until the weevil made its appearance in the terminal shoots. While trying to control this trouble, we switched to red pine which was highly recommended at that time, and we also made some plantings of red and white pine mixed. Then for some years we planted red pine almost to the exclusion of other varieties except for small tracts of Scotch pine, Austrian pine, white spruce, Colorado spruce, Douglas fir and some species which were put in with the idea of being sold when they reached a suitable size for landscape purposes. In the red pine we were sure we had the most suitable all-purpose tree as this variety grew well in any open location except wet ground and no insect or disease had appeared to attack it. We could see our entire holdings on the watershed covered with red pines. But about four years ago, the pine-shoot moth made its appearance. The eggs are laid in the late summer in the new bud, and in the spring when the eggs hatch the worm takes its food from the bud or if it has sprouted from the new shoot. Unlike the white-pine weevil which confines its attention almost entirely to the terminal shoot, the pine-shoot moth attacks any bud and so is more difficult to control, because it is possible to find one or more in every bud on the tree. When it does attack the terminal shoot, the result is the same as in white pine which has been attacked by the weevil, a crooked bole and after repeated attacks a bushy top which crowds out the adjacent straight trees.

These insect troubles with pines compelled us to search for some other variety which was immune to the prevalent diseases and pests. Our experience with spruce was not satisfactory on account of the slow rate of growth in their earlier stages and their sensitiveness to the disease known as spruce gall. Our attention was drawn to the Douglas fir, and our plans for next year call for heavy plantings of this variety. The few small plantings we have made in past years do not show the same rapid growth in early years as do the pines, and many trees have a tendency to throw out more than one terminal shoot, so the Douglas fir is not entirely satisfactory but its freedom from disease makes it attractive. We shall also do some planting of white pine again as the trouble with the weevil has been very slight in the past five years.

In order to avoid destruction of entire tracts by disease, some authorities have recommended planting several kinds of trees in a given area so that if one variety is attacked, the balance will be safe and there will be some trees left to grow into timber. On account of the varying rates of growth of different kinds of trees, this plan did not work out well in many

cases. Pines soon get ahead of spruce and fir and shade them to such an extent that they tend to be choked out or stunted; then there are no trees left but pines.

The combination of red and white pines has been quite satisfactory, as both have substantially the same rate of growth, although after reaching a height of twenty-five feet or so, we seem to think we can see the white pines drawing away from the reds. Of course, the objection to this plan at the present time is that both varieties are subject to disease.

Trees planted 6 by 6 ft. apart number about 1 200 to the acre, but at maturity only 250 to 300 should stand on an acre. This means that many should be removed during their growing period so as to give the tops and roots of those which are left room enough to receive light and nourishment for the trees during their lifetime. If trees are planted closely in the first place, they will be crowded and compelled to put most of the growth upward in the main stem rather than laterally in large branches. By close planting, the branches that do develop are interlocked and die from lack of sunlight. This makes for small knots in the timber and then only in that section of the lumber which comes from the center of the log.

We have one small tract of white pine which was thinned this past winter to 600 to the acre. This was necessary not on account of the age of the trees but because weevil had been active in earlier years, and after repeated attacks the tops had become so bushy that they were crowding out and topping straight trees. This tract before thinning presented quite a sorry appearance, as the dominating trees were the crooked and bushy ones and one would conclude at first sight that the tract was practically worthless as a timber proposition; but when the work had been completed and the number standing had been reduced from 1 200 to 600 to the acre, it was found there would be more than a sufficient number of good trees to make the required quota of 250 to 300 at maturity. This experience showed us that the devastations of the weevil had not been serious enough to ruin the whole plot of white pines as a timber project, even though the pest had affected more than half the trees, because in an original planting of 1 200 to the acre only about one-fourth can remain until fully grown. This shows one reason why we are considering favorably the renewed planting of white pine.

Everyone engaged in reforestation work has undoubtedly encountered trouble in planting trees on land overgrown with goldenrod or heavy weeds, lately abandoned meadows and recently cut-over land. In these locations, many of the trees are choked out while still small by the dense growth of grass, weeds or brush. This can be prevented, of course, by mowing between the trees for a few years, but our experience has shown this to be too expensive for a forestation project. We believe this problem can be solved by the use of whitewood or tulip. We have found it advisable, after these trees are received as seedlings from the dealer, to keep them in a transplant bed for one year to develop a more satisfactory root system.

The trees grow very rapidly and are quite tolerant to shade. Thus they are able to force themselves through the other vegetation into the open. They are an excellent timber tree and on account of their straight vertical trunks make a handsome appearance. The whitewood is not dissimilar from evergreens in that it has its own particular disease in the nature of a scale. With the white pine affected by weevil and the gloriola fly, the red pine and Scotch pine by the pine-shoot moth, all the spruces by the spruce gall, the Douglas fir by its tendency to grow into a bush or throw out more than one terminal shoot, and the whitewood by the scale, it can be seen that of the varieties we have tried none has been entirely satisfactory.

Related to the forestry project only because it concerns trees is the development of an orchard on a particularly well situated hillside. From a small beginning, it has grown into an extensive area of apple and peach trees with the necessary packing and grading sheds and cold storage plant. While all the peaches have been marketed this year, most of the apples are on the trees or in the cold storage plant. The work in the orchard and nursery is carried on by the same force of men who look after two reservoirs and do most of the work of operation, maintenance and minor construction on the watershed. All these projects are handled from one base, and this arrangement makes for particularly economical and orderly operation.

Discussion.

Truman M. Curry, Jr.* I noticed with interest that Mr. Pollitt did not refer to the white pine blister rust.

Mr. Pollitt. We have never seen a bit of it in this part of the country.

Mr. Curry. I have some white pine on my own place in Watertown, Conn., about 40 miles from here, and have had a serious fight to control blister rust. I finally had the State eradicate the currant bushes for several thousand feet distant. I know that on the Waterbury watershed the white pine growth, for a number of years, was seriously threatened by white pine blister rust, but I understand that they have got the upper hand of it by clearing out the wild currant. Has the Bridgeport Hydraulic Company tried hemlock in its plantings?

Mr. Pollitt. Not so far. We have some hemlocks in the nursery, which we hope to sell for ornamental trees, but we have never set them out in the forest because we could find other trees which would produce lumber which was more desirable.

Mr. Curry. Of course hemlock lumber is not worth much, but as a beautiful tree quite free from disease in this part of the country it is, I think, worth considering.

H. W. Griswold.† Only a small portion of your watershed is set out in pines, isn't it?

* Watertown, Conn. † Hartford, Conn.

MR. POLLITT. Yes, a comparatively small part of the total area. On the other hand, the greater percentage of the watershed is in natural timber. You probably have in mind the matter of thinning the native timber and trying to improve the stand.

MR. GRISWOLD. Thinning, marketing, and fire protection.

MR. POLLITT. With reference to thinning, we have found that we can hardly afford it on account of the expense of thinning and because the kind of material which comes from our premises, which may be different from some other places, is not suitable for marketing. We can thin close to the reservoirs, where the overseer makes use of it for fuel. But we have never been able to find the proper kind of wood in the thinnings which can be marketed. We have sold a considerable quantity of wood, in the past. At that time we had a maple swamp which had reached maturity over a good many acres, and we cleaned it out completely. We have not had to cut any wood for sale in the last two or three years. In the case of white wood, my personal experience is, that it is better to go into a lot that is pretty well matured or that has trees of all ages in it, and to cut it completely, and then immediately to set out white wood again.

MR. GRISWOLD. Do you know if the Austrian pine is immune to the pine tree moth?

MR. POLLITT. We have very few Austrian pines, and the particular part of the country where this tree is planted has not yet been reached by the pine tree moth.

MR. THEODORE L. BRISTOL.* What have you done to control the pine-shoot moth?

MR. POLLITT. In the spring of the year we usually get a force of men and go over the trees and take the affected buds off while the worm is still in them, after they have reached a stage which shows which ones are affected. That works very well with trees up to 4 to 6 ft. high. There was quite an improvement shown this spring over last year in the condition of the trees of these smaller sizes. But when trees reach a height of 20 or 25 ft. it becomes more troublesome. We tried last year by using shears to trim off the shoot or cluster. This year, on account of the expense of shearing trees, we did not do it.

MR. BRISTOL. Do you do anything with them in the fall?

MR. POLLITT. No. I understand that the Westchester County, New York, park system has developed a spray which will eradicate the moths when they are about. The use of a spray will work very well on the trees in a park, but I do not know how you would get into a forest to spray in a proper manner.

H. J. COOK.† Have you done anything to control the pine weevil?

MR. POLLITT. Yes. Whenever we find a pine weevil we take the

* Ansonia, Conn. † Auburn, Me.

terminal shoot off and burn it. We have had very little trouble of late. I have not seen one this year.

MR. GRISWOLD. Have you done any planting work in inferior hardwood stands?

MR. POLLITT. A few years ago we did; but the planted area was neglected, and the trees, put out in 1910 to 1912 are only about 3 ft. high today. They are completely stunted. We do not plant evergreens on cutover land on account of the fact that the brush must be cleaned up every year for a number of years to give the evergreens a chance to come through. As I said, we think white wood is preferable in cases of that kind.

MR. GRISWOLD. How far apart do you plant the white wood?

MR. POLLITT. We plant them 6 by 6 ft. apart, the same as the other trees, probably because it is habit. There is no particular reason that I know for it.

PRESIDENT ELLIS. I would like to ask Mr. Pollitt whether he makes any preparation for the planting of the evergreens.

MR. POLLITT. A number of years ago we used to cut off the brush. Now, where we have land with clumps of bushes on it, we do not touch them, but plant with evergreens, keeping them about 6 to 10 ft. away, depending on the size of the brush, so that the trees will have a chance to grow without being shaded. Eventually the inferior growth of white birch or other varieties will be removed to give the new trees a chance to grow.

MR. BRISTOL. Haven't you found that where the pine was planted with hard wood you have not been troubled with the weevil?

MR. POLLITT. I do not know that we have any situations like that. Our trouble with the weevil was a great many years ago. I do know that it was worse where there was solid white pine than where there was a mixture with red pine or some other tree. I do not believe we have any situation where white pine was mixed with hard woods.

RELATION OF FORESTS TO THE EVAPORATING POWER OF THE AIR.[1]

PAUL W. STICKEL.*

[*Received June 27, 1933.*]

In the Northeast, with its ever growing, densely populated urban sections, the problem of furnishing adequate domestic water supplies has and will continue to become increasingly acute. As a corollary it follows that every possible means must be employed to conserve available water supplies. It is the purpose of this paper to show that forests, because of their modifying influence upon the factors which bring about water loss in the form of evaporation from the soil, have a very important role in any system of watershed protection.

A portion or all of the water precipitated over an area may be prevented from eventually reaching the lower strata of the soil and swelling underground seepage by one or a combination of several factors. Precipitation may be dissipated through interception by the foliage of the living vegetation, whence a part of the water may be re-evaporated into the air; precipitation may be evaporated from the surface of the ground; precipitation may pass into the streams as surface run-off; and precipitation may be absorbed by the living vegetation, which uses part of the water for nutritive purposes and transpires the rest into the air. American investigators of the relationship between forests and water, such as Bates and Henry([1]), Lowdermilk ([2, 3]), and Zon ([5]) have been interested primarily in investigating the protective influence of forests through their binding of the soil and their covering it with litter and humus, thereby (1) preventing erosion, and (2) exerting a modifying effect upon the run-off and percolation of precipitation. Practically no comprehensive data have been presented showing the influence of forests upon the evaporating power of the air, a factor which may serve as a fairly reliable index to the relative loss of water evaporated from the surface of the ground. The data included in this paper show how markedly the presence of the forest canopy modifies this factor.

Description of Forest Areas and Instrumentation.

Forest Areas. During the period 1925 to 1930 inclusive, the Northeastern Forest Experiment Station conducted a study of forest-fire weather

*Associate Silviculturist, Northeastern Forest Experiment Station.[2]

[1] In this paper it is postulated that air, or more properly speaking space, because of its ability to absorb moisture has a distinct evaporating power. This power is largely dependent upon temperature since the moisture-holding capacity of air doubles approximately with each increase of 18° F.

[2] Maintained by the U. S. Department of Agriculture at New Haven, Conn., in coöperation with Yale University.

in several of the forest regions of New England and New York.[1] Field work in this investigation entailed the establishment and maintenance of duplicate meteorological stations in clear-cut areas and within adjacent stands of green timber. In the discussion which follows, the term "open stations" refers to those situated in the fully exposed areas and the term "forest stations" to those within the standing timber. At none of the four experimental areas did the distance between open and forest stations exceed 500 ft., nor was there any appreciable difference in elevation at the individually paired stations.

The description of forest conditions at the four fire-weather stations can be summarized briefly as follows:

1. Cranberry Lake, New York, in the west central part of the Adirondack Mountains; elevation, 1 620 ft. above sea level; forest type, culled, over-mature mixed northern hardwoods — beech, yellow birch, and sugar maple (*Fagus grandifolia* Ehrhart, *Betula lutea* Michaux, and *Acer saccharum* Marshall) with a scattering of younger red spruce (*Picea rubens* Link) and balsam fir (*Abies balsamea* (Linnaeus) Miller); open station located in circular clearing having a radius of about 150 ft.
2. Elk Lake, New York, in the east central part of the Adirondack Mountains; elevation, 2 100 ft. above sea level; forest type, small pole, upper slope red spruce-balsam fir with some northern white cedar (*Thuja occidentalis* Linnaeus); open station located in an old woods road having a width of 30-40 ft. and running due east and west.
3. Petersham, Massachusetts, in the north central part of the state; elevation, 850 ft. above sea level; forest type, 80-year old merchantable mixed white pine and eastern hemlock (*Pinus strobus* Linnaeus and *Tsuga canadensis* (Linnaeus) Carriére); open station located in a strip-clearing measuring approximately 400 ft. by 100 ft.
4. Smyrna Mills, Maine, in northeastern part of the state; elevation, 580 ft. above sea level; forest type, young merchantable red spruce-balsam fir with some white spruce (*Picea glauca* (Moench) Voss) and some beech, yellow birch, and sugar maple; open station consisted of a clearing about 75 ft. square located in an area where all mature softwoods had been removed, leaving a scattering of hardwoods and young conifers.

Instrumentation. The measurement of the three meteorological factors discussed in this paper was done with standard ecological instruments. For indicating the evaporating power of the air, Livingston atmometer bulbs, equipped with non-rain-absorbing mountings, were used. At each individual station a battery of two atmometers was used. All evaporation data are based, therefore, upon the averages of two instrumental readings. These instruments were so placed that their evaporating surfaces were approximately at the same level as the surface of the litter and duff layer of the forest floor. Standard mercurial thermometers of a good grade were used to measure surface-duff and top-soil temperatures. The duff thermometers were placed just beneath the surface of the organic débris so that the bulbs were covered at all times. In taking soil temperatures, the ther-

[1] The following agencies coöperated in these fire-weather studies: The New York State College of Forestry; the Conservation Department, State of New York; the Empire State Forest Products Association; Finch, Pruyn and Co., Inc.; the Harvard Forest; and the Maine Forest Service.

mometer bulbs were so situated that the instruments measured the temperature of the first 1-inch soil layer below the duff horizon.

Instrumental readings were taken four times daily, at 8:00 and 11:00 A.M., and at 2:00 and 5:00 P.M. Care was taken to see that the instruments occupied the same place on the ground during the entire course of the investigation.

The Effect of Forest Cover Upon Water Loss From Duff and Soil.

Evaporation. Average monthly open and forest evaporation data are contained in Table 1. The differences between these paired measurements are brought out even more clearly by their graphical presentation as in Figure 1. The variations between evaporation in the open and within the

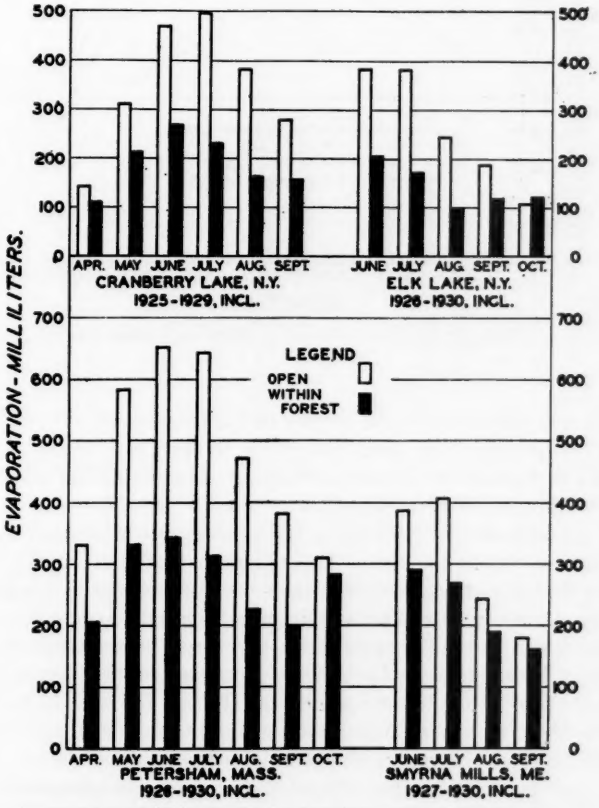

Fig. 1.—Effect of Forest upon Evaporation.

forest under the same general type of weather are so wide and consistent as to lead logically to the following conclusions:

1. During the late spring, the entire summer, and the early fall months, the evaporating power of the air in the open far exceeds that within the forest. The ratio between open and forest evaporation becomes proportionally greater from late spring to summer, reaches its peak generally during

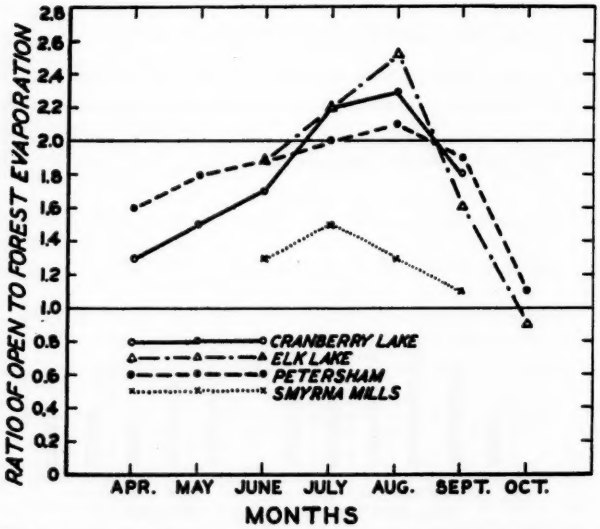

FIG. 2.—AVERAGE MONTHLY RATIOS OF OPEN TO FOREST EVAPORATION.

August, and declines with the coming of fall (see Fig. 2). On the average during this period of the year (late spring to early fall inclusive) between 1.3 and 1.8 times as much water is evaporated by the air in the open as by the air within adjacent forest stands.

2. In only one case did the average monthly evaporation within the forest exceed that in the open. This exception was noted at the Elk Lake stations during October and illustrates the culmination of a similar tendency shown in the Petersham and Smyrna Mills data — namely, a gradual equalization in the fall between open and forest evaporation which may eventually lead, as shown by the Elk Lake data, to greater evaporation within the forest than in the open during the late fall and winter months.

One of the causes of the inversion mentioned may be attributed to the well known effect of forest cover upon the temperature of the air, duff, and soil;* it lowers the daily mean temperature in spring and summer and raises

(*See Toumey, pp. 205-211)

it slightly in fall and winter. Since the rate of evaporation varies directly with temperature, it is logical to expect that the evaporating power of the air will follow the seasonal temperature changes within the forest. At Elk

TABLE 1.— AVERAGE MONTHLY EVAPORATION IN OPEN AND WITHIN THE FOREST.

Month.	Evaporation — Milliliters.		Ratio of open to forest evaporation.
	In open.	Within forest.	
A. *Cranberry Lake, N. Y., 1925–1929, inclusive.*			
April[1]	140.10	106.26	1.3
May[2]	309.16	212.28	1.5
June[3]	469.12	274.74	1.7
July[3]	498.22	227.70	2.2
August	382.67	163.27	2.3
September	277.10	156.64	1.8
Season Summary	2 076.37	1 140.89	1.8
B. *Elk Lake, N. Y., 1926–1930, inclusive.*			
June[3]	385.41	202.72	1.9
July	382.22	170.52	2.2
August	243.29	96.51	2.5
September[3]	186.24	115.62	1.6
October[1]	106.30	117.76	0.9
Season Summary	1 303.46	703.13	1.8
C. *Petersham, Mass., 1926–1930, inclusive.*			
April[2]	331.07	205.25	1.6
May	581.44	330.15	1.8
June	649.12	340.42	1.9
July[3]	640.44	314.98	2.0
August[3]	467.57	225.56	2.1
September[3]	380.75	196.82	1.9
October[3]	309.18	279.13	1.1
Season Summary	3 359.57	1 892.31	1.8
D. *Smyrna Mills, Me., 1927–1930, inclusive.*			
June	386.46	286.53	1.3
July	405.77	266.43	1.5
August	240.82	188.68	1.3
September	179.38	160.87	1.1
Season Summary	1 212.43	902.51	1.3

[1]2-year average. [2]3-year average. [3]4-year average.

Lake, winter climatic conditions occur at least one month earlier than at the remaining stations.

A further study of the data contained in Table 1 and Figure 2 discloses

one additional point of interest which stresses the importance of keeping the forest cover of mountainous areas intact — namely, the effect of forests upon the evaporating power of the air seems to become greater not only with increase in seasonal temperature but also with increase in altitude. It will be noticed in Figure 2 that the influence of forests upon the evaporating power of the air is greatest during the warmest months at the two stations having the higher elevations, *i. e.*, Cranberry Lake and Elk Lake. Furthermore, of these two stations, Elk Lake is considerably higher in elevation than Cranberry Lake (2 100 ft. as compared to 1 620 ft.) and here again the greater influence of forest upon evaporation is indicated for the higher station, Elk Lake. This effect is all the more worthy of note if it is remembered that general climatic conditions are much warmer at Petersham, for example, than at Elk Lake. The fact that the average open evaporation during August at Petersham is almost twice that at Elk Lake for the same month (467.6 ml. compared to 243.3 ml.) substantiates this statement. Yet, whereas at Petersham the August ratio of open to forest evaporation is 2.1, it is 2.5 or almost 20 per cent. greater for the same month at Elk Lake.

Duff and Soil Temperatures. In the preceding sole consideration has been given to the effect of forest cover upon reducing water loss from the ground by reducing the evaporating power of the air. Striking as this influence is, it may be of no more importance than the influence of other factors which control evaporation from the ground.

The evaporation from duff-covered and bare-soil surfaces accounts for a very considerable amount of the water which is lost to underground seepage. The percentage of precipitation displaced in this manner depends upon the type of soil and the presence or absence of a cover of organic débris. For example, according to Zon* certain European investigators have found that the evaporation from bare, sandy soil and from clayey soil in the open amounts to 33.6 and 50.8 per cent. respectively. Likewise, it has been found that the evaporation from a sandy soil without a cover of leaf litter is 39, and with a cover only 15.4 per cent. of the amount evaporated by a similar soil in the open.

Since heat is necessary in any evaporating process, it follows that any agency which will reduce duff and soil temperatures, will likewise bring about a reduction in evaporation from these materials. Because of their non-cumulative nature, open and forest duff- and soil-temperature data cannot be presented in quite the same manner as the foregoing evaporation data. Nor are monthly averages — whether they be of a maximum, minimum, or mean nature — adequate to illustrate the difference in the heat absorbed by duff and soil in the open and within the forest. A satisfactory method of bringing out the total effect of forest upon duff and soil temperature may be obtained by multiplying the temperature differences for the hours covered by the observations by the period for which they were

(*pp. 26-27)

effective. In summing the differences in this way the author has considered the total difference for each three-hour period as three times the average of the differences at the beginning and end of the period. The cumulative temperature difference for each month was averaged for the years in which data were obtained. The average hourly temperature difference was obtained by dividing the average cumulative monthly temperature difference

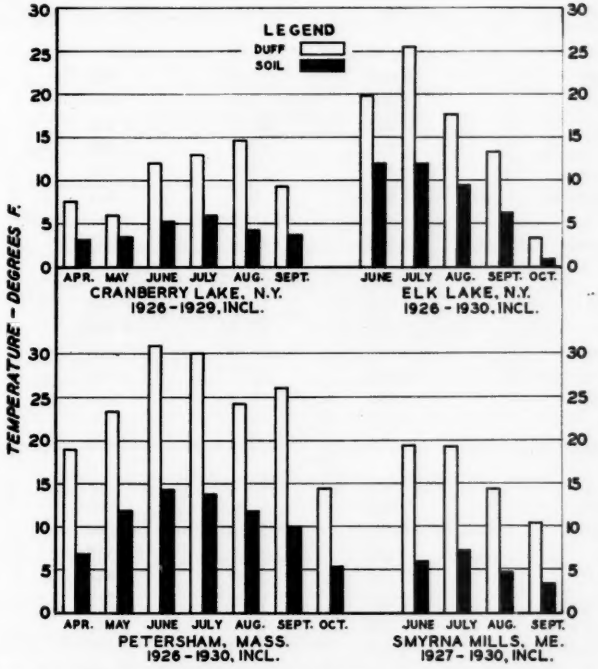

FIG. 3.—AVERAGE EXCESS IN HOURLY DUFF AND SOIL TEMPERATURE DIFFERENCES IN OPEN OVER FOREST FOR HOURS BETWEEN 8:00 A.M. AND 5:00 P.M. DAILY.

by the number of days for the month in question and then dividing the quotient by 9 for the number of hours involved (8:00 A.M. to 5:00 P.M. inclusive).

Table 2 contains the results of these computations, while in Figure 3 will be found a graphical presentation of average hourly duff- and soil-temperature differences between open and forest area. The latter data are particularly illuminating, ranging as they do in the case of the duff temperatures from a maximum hourly difference of 30.9° F. during August at Petersham to a minimum hourly difference of 3.2° during October at

Elk Lake; for the soil temperatures, the maximum and minimum values — 14.2° and 0.7°— are coincident with the maximum and minimum duff-

TABLE 2.— CUMULATIVE EXCESS OF DUFF AND SOIL TEMPERATURES IN OPEN OVER FOREST BETWEEN 8.00 A.M. AND 5.00 P.M. DAILY.

Month.	Duff.		Soil.	
	Average cumulative monthly temperature difference—°F.	Average hourly temperature difference—°F.	Average cumulative monthly temperature difference—°F.	Average hourly temperature difference—°F.
A. *Cranberry Lake, N. Y., 1926–1929, inclusive.*				
April[1]	2 019	7.5	840	3.1
May[2]	1 659	5.9	914	3.3
June	3 228	12.0	1 410	5.2
July	3 886	13.9	1 680	6.0
August	4 107	14.7	1 220	4.4
September	2 516	9.3	971	3.6
Seasonal Summary	17 415	10.6	7 035	4.3
B. *Elk Lake, N. Y., 1926–1930, inclusive.*				
June[3]	5 327	19.7	3 224	11.9
July	7 079	25.4	3 224	11.9
August	4 917	17.6	2 610	9.4
September[3]	3 555	13.2	1 648	6.1
October[1]	896	3.2	184	0.7
Seasonal Summary	21 774	15.8	10 890	7.9
C. *Petersham, Mass., 1926–1930, inclusive.*				
April[2]	5 093	18.9	1 827	6.8
May	6 497	23.3	3 299	11.8
June	8 353	30.9	3 846	14.2
July[3]	8 383	30.0	3 844	13.8
August[3]	6 740	24.2	3 282	11.8
September[3]	7 025	26.0	2 661	9.9
October[2]	4 019	14.4	1 467	5.2
Seasonal Summary	46 110	23.9	20 226	10.5
D. *Smyrna Mills, Me., 1927–1930, inclusive.*				
June	5 249	19.4	1 589	5.9
July	5 374	19.3	1 983	7.1
August	3 994	14.3	1 270	4.6
September	2 773	10.3	875	3.2
Seasonal Summary	17 390	15.8	5 717	5.2

[1]2-year average. [2]3-year average. [3]4-year average.

temperature differences cited. Finally, it will be noticed that the reductions in duff- and soil- temperatures are materially smaller in the case of hardwood than softwood stands. For the hardwood type of forest cover (Cranberry

Lake) a seasonal average hourly duff and soil temperature difference of 10.6° and 4.3°, respectively, is indicated; for the softwood type of forest cover (Elk Lake, Petersham, and Smyrna Mills) the seasonal average hourly duff-temperature difference varies from 23.9° to 10.5° and for soil temperature from 15.8° to 5.2°.

Selected duff- and soil-temperature data presented in Figure 4 further illustrate the extent to which coniferous forest canopies modify these elements, and how effectively they prevent the surface-duff and top-soil layers beneath the tree crowns from reaching the extremely high tempera-

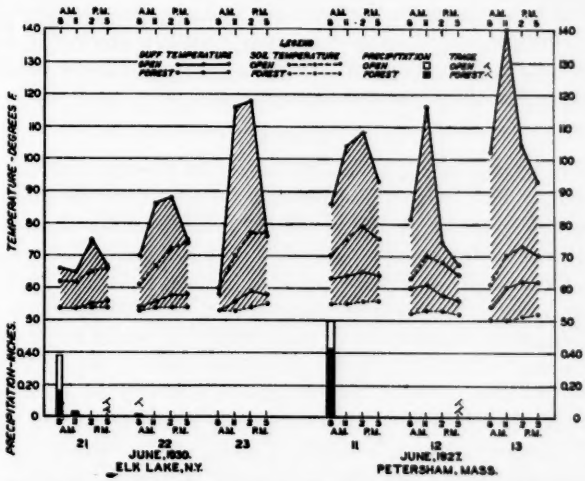

FIG. 4.—EFFECT OF FOREST UPON DUFF AND SOIL TEMPERATURE.

tures attained in the open. The differential between open and forest surface-duff temperature is very striking. It can amount to as much as 80°, as for example at Petersham on June 13 at 11 A.M. Between open and forest top-soil temperatures the difference is less marked; yet, it may be almost 25° (see Petersham, June 11 at 2:00 P.M.). Even the mere presence of the duff carpet over the soil in the open protects the soil beneath from high temperatures. This duff layer, which at Petersham averaged 2½ inches in thickness and at Elk Lake about 2 inches, being dark-colored and opaque, reflects but little of the insolation which falls upon it, transmits practically none, and thus absorbs nearly all in a thin surface layer. Referring once again to the 2:00 P.M. data of June 13 at Petersham, it will be seen that the difference between open surface-duff and top-soil temperatures is 70° F.

In addition to illustrating the broad effect of forest canopy upon duff and soil temperatures, Figure 4 indicates how much greater the evaporation after precipitation must be in the open than within the forest. Both of the series in Figure 4 start with rainy periods, during which the surface-duff

temperatures in the open and within the forest do not vary more than 20°. After precipitation has ceased and fair weather has set in, surface-duff temperature within the forest is maintained at a fairly uniform level which does not fluctuate more than 10° during the day. In the open an entirely different condition is to be found. Within 24 hours after precipitation, the rise in early-morning surface-duff temperature in the open can reach almost 60°, as was the case between 8:00 and 11:00 A.M. at Elk Lake on June 23. The rate at which any water left in the duff by the previous precipitation is lost under this change in temperature must be materially greater than within the forest with its uniformly low duff temperature. This extremely rapid rise in duff temperature in the morning hours in the open must likewise have the effect of rapidly evaporating any moisture which is deposited on the ground in the form of dew or hoarfrost, thereby removing an additional means of keeping the upper soil layers moist.

SUMMARY.

It is to be expected that water losses from forested and non-forested areas should differ. Within the forest, in contrast to the open, surface run-off and evaporation from the soil are much reduced. However, trees intercept some of the precipitation thus preventing all of the water from reaching the ground. Moreover, some of the soil moisture is returned to the air by trees in the form of transpiration. In this paper no attempt has been made to evaluate all of these influences which bring about differences in water losses within forests as compared to the open: sole consideration has been given to the influence of forests upon only one of the many interrelated factors — the evaporating power of the air. The data show that in openings, even if only very small, almost twice as much water will be evaporated than beneath forest cover. Likewise, the trees so effectively shade the ground that duff and soil beneath the crowns are never heated to the high temperatures created in the open. This reduction in duff and soil temperatures must have an appreciable effect in reducing evaporation from duff and soil. The lack of other pertinent data makes it impossible to compare the reduction in the evaporating power of the air attributable to forest cover with water lost by interception or transpiration.

REFERENCES.

[1] Bates, C. G., and Henry, A. J. 1928. Forest and stream-flow experiment at Wagon Wheel Gap, Colo. Final report on completion of second phase of the experiment. Mon. Weather Rev., Sup. No. 30, 79 p., illus.

[2] Lowdermilk, W. C. 1930. Influence of forest litter on run-off, percolation, and erosion. Jour. For. 28:474–491, illus.

[3] Lowdermilk, W. C. 1933. Forests and streamflow, a discussion of the Hoyt-Troxell report. Jour. For. 31:296–307, illus.

[4] Toumey, J. W. 1928. Foundations of silviculture upon an ecological basis. 438 p., illus. J. Wiley & Sons, Inc., New York.

[5] Zon, R. 1927. Forests and water in the light of scientific investigation. Appendix V, Final Report of National Waterways Commission, 1912. Senate Document No. 469, 62nd Congress, 2d Session, 106 p. illus.

WAKEFIELD WATER SUPPLY.

BY ROBERT SPURR WESTON.*

[*Received September 25, 1933.*]

The Town of Wakefield, Mass., lying in the zone of rapid suburban growth in the Boston Metropolitan District, has, like other towns, faced the problem of a better water supply and made certain improvements, which are described in the following:

Population and Water Consumption. The population of Wakefield has increased in thirty years from 9 290 to over 16 318, which was the population in 1930. This is a greater increase than was generally estimated ten years ago. The water consumption has likewise increased, although at a lower rate than the population. It averaged 763 400 g.p.d. in 1932. At times the maximal consumption exceeds 1 250 000 g.p.d.

Sources of Supply. The main source of supply is Crystal Lake which is fed by springs and brooks. Parts of the courses of the latter drain quite highly populated residential districts. The lake has an area of 82.7 acres, or 0.12 sq. miles, and stores 303 m.g. of water. The catchment area of the lake is 1.17 sq. miles and the mean annual rainfall 44.45 in. This provides a safe yield of about 700 000 g.p.d.

Because of the inadequacy of the lake in a dry period, 50.34 m.g. of water had to be taken from the Boston Metropolitan Supply in the dry year of 1930. Since then the town has partially developed a well field in the vicinity of the Town Farm gravel pit, in the area between Nahant Street and Wakefield Brook, a tributary of the Saugus River.

At present this area can furnish about 50 m.g. a year, or about 140 000 g.p.d., but can readily be developed to supply at least 350 000 g.p.d., making a total available supply with Crystal Lake of over 1 m.g.d. which is adequate until after 1945, even assuming the occurrence of another dry period before that time. The quality of the ground water from this area is excellent.

The average daily consumption in the year 1932 was 763 000 gals., and given normal years Crystal Lake alone is adequate for the supply of the town for a dozen years ahead. The yield of the lake may be increased by raising the upper part by a dam, but in view of the available and more economical ground water, this is not advisable.

Quality of Water. The easterly side of Crystal Lake is well protected by sewers; but the tracks of the Boston and Maine Railroad also traverse this side. The lower or northeasterly side of the lake is fairly well protected by lands owned by the town, but considerable pollution enters the upper part, especially through the feeder brooks. The southerly shores of

*Of Weston and Sampson, Consulting Engineers, Boston, Mass.

the lake are swampy and contribute some color. Since about 1915, the water supplied to consumers has been disinfected with chlorine applied at the pumping station, and since 1924, it has also been the practice to apply this chemical to the water entering the lake through the main feeders.

The significant characteristics of the Crystal Lake water are shown in Tables 1 and 2.

TABLE 1.— CHARACTER OF CRYSTAL LAKE WATER.
(Parts per million.)

Year.	Turbidity.	Color.	Chlorides.	Hardness.	Iron.	Oxygen Consumed.	Micro-organisms, per cc.
1928	7	24	8.9	25.9	0.14	...	631
1929	5	22	9.0	26.9	0.18	2.7	928
1930	4	18	9.4	28.8	0.21	3.0	615
1931	6	25	9.2	34.7	0.33	3.0	630
1932	4	19	9.5	34.3	0.21	3.3	1 118

TABLE 2.— BACTERIAL CHARACTER OF CRYSTAL LAKE WATER.

Year.	MEAN BACTERIA PER CC.		BACT. COLI. PER CENT. POSITIVE TESTS.		
	at 20° C.	at 37° C.	in 0.1 cc.	in 1.0 cc.	in 10 cc.
1926	309	71	0	0	12.3
1927	119	70	0	20	16.7
1928	108	78	0	0	8.0
1929	50	26	0	0	8.0
1930	219	81	0	0	12.0
1931	363	119	0	0	9.3
1932	294	115	0	5.5	15.5

The increasing chlorides, hardness and oxygen consumed apparently evidence an increasing population on the catchment area, while the bacterial character of the water is greatly modified by the chlorination of the brooks feeding the lake. Since the purification works were constructed, the degree of application has been lessened, resulting in some increase in pollution at the intake. A careful study of the bacteriological data shows that the increase in pollution of the lake is not alarming, indicating that, with reasonable precautions, it may serve as a source of water supply for Wakefield for many years to come, even after increasing consumption requires that it be supplemented with water from other sources.

At times, growths of microörganisms have imparted odors and tastes to the water. Often these have caused serious complaint, the water at times possessing a greasy-fishy odor, due to *Dinobryon* and *Asterionella*. On other occasions, the water has been alive with the crustacean, *Cyclops*, a diminutive but visible cousin of the lobster, and while this organism is often found in good waters, the effect of large numbers dying-out in the mains and decomposing is far from agreeable. In the past, the growth of organisms has been controlled by treatment with copper sulphate, but this is impracticable when the lake is covered with ice and certain objectionable organisms abound; hence the necessity for aëration and filtration to control their growth.

Having set aside the proposition to participate in the Boston Metropolitan Supply, partly on account of its greater cost, partly because Wakefield possesses a valuable asset in its present supply, and partly because of the superior quality of purified Crystal Lake water, the water board and later the town adopted the recommendation of its engineers, and in 1927 constructed a water-purification plant, consisting of aërators, slow filters and the necessary connections.

Water Purification Plant. The general plan of the water-purification plant is shown in Figure 1 and parts of the plant are illustrated in Figures 2 and 3. The plant may be described as follows:

The plant takes its water through two, parallel, 14-in. cast-iron pipes extending respectively about 300 and 500 ft. from the shore of the lake at the pumping station into 12 and 20 ft. of water. These two pipes are the suction mains for two low-lift pumps which deliver untreated water to the aërators at the purification plant. After aëration to remove objectionable odors and tastes, the water flows by gravity to two slow sand filters where the final purification takes place. The filters discharge into two filtered-water basins located beneath the aërators.

The high-lift pumps, located in the pumping station with the low-lift pumps, deliver the water to the distribution system and standpipes.

Pumping Equipment. Duplicate low-lift, Gould, 10 in., horizontal, centrifugal pumps are directly connected to 15-h.p., General Electric motors. The capacity of each pump is 2 500 000 g.p.d. One pump alone is operated, with the other held in reserve for emergency. Duplicate, high-lift, Gould, 8 in., horizontal centrifugal pumps are directly connected to 150-h.p., General Electric motors. The capacity of each pump is 2 500 000 g.p.d. Ordinarily one pump is operated, although both may be used simultaneously, thereby increasing the rate of pumping to about 5 m.g.d., or the equivalent of twelve standard fire streams in addition to the ordinary domestic consumption.

When these pumps were installed, one of the existing steam pumps was removed. The other steam pump and the boilers are kept in reserve for emergency use during interruption of the electric power supply.

Sundh fire panel and control with main oil-brake switch, fused knife

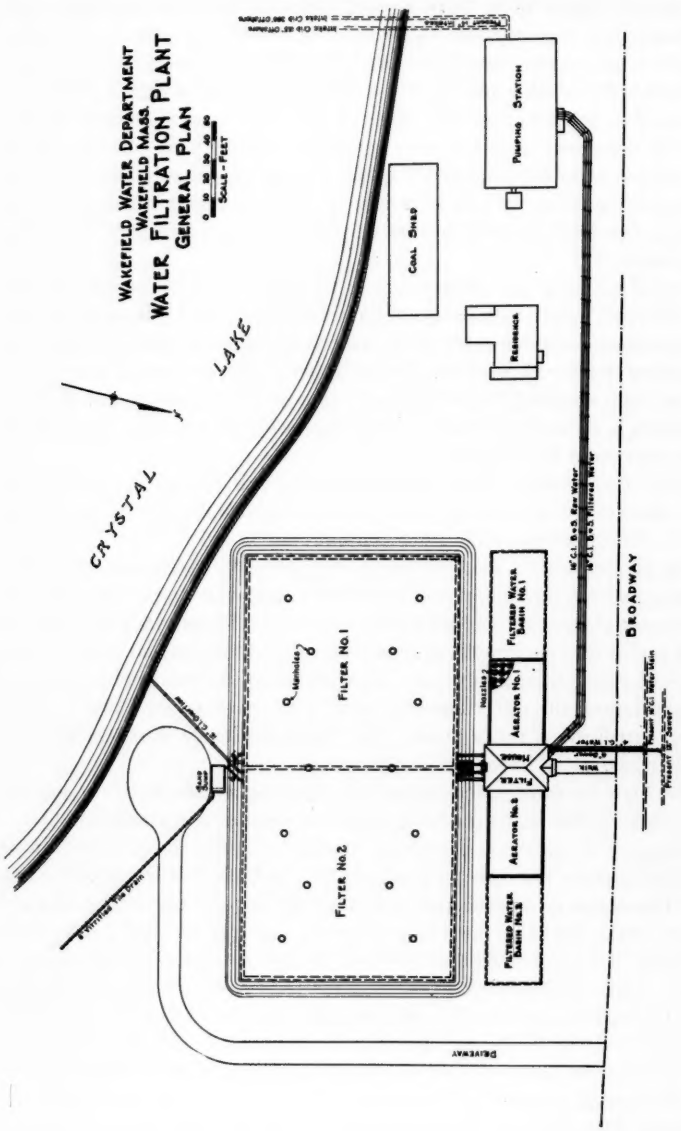
WAKEFIELD WATER DEPARTMENT
WAKEFIELD MASS.
WATER FILTRATION PLANT
GENERAL PLAN
SCALE - FEET
LAKE
CRYSTAL
COAL SHED
POWER STATION
RESIDENCE
FILTER NO. 1
FILTER NO. 2
Manholes
FILTERED WATER BASIN NO. 1
AERATOR NO. 1
AERATOR NO. 2
FILTERED WATER BASIN NO. 2
HOUSE
BROADWAY
DRIVEWAY

FIG. 1.

switches, automatic time-limit starters, overload and low-voltage protection, automatic-stop switch for the high-lift pumps, indicating volt and watt meters, etc., constitute the equipment of the switchboard.

Aërators and Filters. There are two aëration units, each 28 ft. by 44 ft. in area, and equipped with 77 2-in., special, bronze aërator nozzles, each with 22 5/32-in. holes.

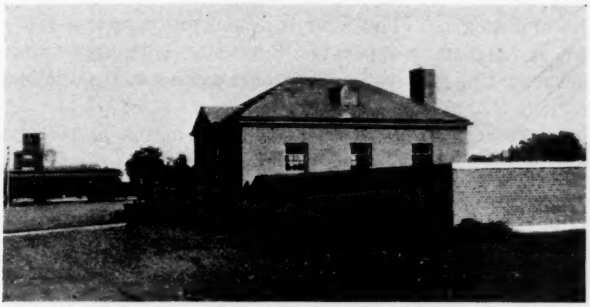

FIG. 2.— FILTER HOUSE AND AËRATOR.

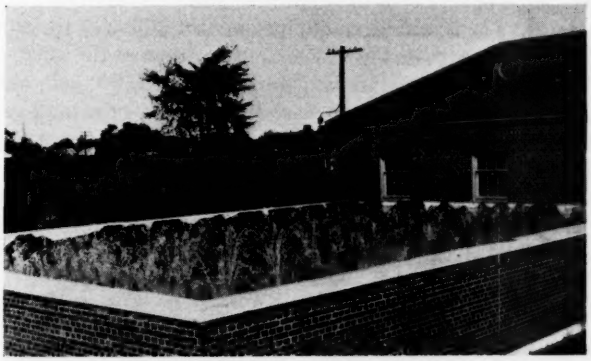

FIG. 3.— AËRATOR, SHOWING SPRAYS.

There are two filter units, each 108 ft. 3 in. square or one-half acre in net area, built of plain concrete and containing the usual filtering layer and underdrains. The roofs are groined arches supported by the walls and columns; the floors are also groined. The depth of water above the sand is 4 ft., rising to the springing line of the arches.

The fiter sand, dredged from the bed of the ocean off Ipswich, Mass., is 3 ft. in depth with an effective size of 0.35 mm., and a uniformity coefficient of 1.5. The sand is supported on a 12-in. layer of screened and

washed gravel of three sizes. The top layer, 2 in. in depth, was retained on a screen having 12 meshes per lineal inch and passed a ¼ in. screen. The middle layer, 3 in. in depth, was retained on a ¼ in. screen and passed a ¾ in. screen. The bottom layer, resting on the floor of the filters, and 7 in. in depth, was retained on a ¾ in. screen and passed a 2 in. screen. The roof of the filters is covered with 12 in. of earth fill and 6 in. of loam, with several manholes for access, light and ventilation.

The capacity of the plant is 2.5 m.g.d. and the filter area is designed for a rate of 5 m.g.a.d. The filter control-house contains the operating equipment and recording apparatus. Each filter is equipped with an indicating and recording rate-of-flow controller and an indicating loss-of-head gauge.

When sufficient organic or other suspended matter has accumulated at the surface of the sand to increase the loss-of-head to from 5.5 to 6.0 ft., the filter is unwatered and either raked or scraped, depending upon the condition of the sand and the character of the suspended matter causing the clogging of the filter. After cleaning, the filter is refilled from below and placed in service.

Filtered-Water Basins. The two filtered-water storage basins are each 28 ft. by 99 ft. 10 in. in area, and at the maximal depth of 12 ft. contain a total of 500 000 gal., thus providing a supply of filtered water for emergency use especially while the filters are being cleaned.

Standpipe. The new steel standpipe on Hart Hill is 47 ft. in diameter and 50 ft. in height, with its top at the same elevation as the existing standpipe. The capacity of the Hart Hill standpipe is 650 000 gal., and of the old standpipe, near the Stoneham line, 580 000 gal., or a total storage of 1 230 000 gal. The new standpipe, located nearer the business center, has considerably increased and stabilized pressures throughout the easterly portion of the town.

Results of Operation. The pertinent results of nearly five years of operation are given in Tables 3 and 4.

TABLE 3.— AVERAGE CHARACTER OF WATER DELIVERED TO MAINS.
(Parts Per Million.)

Year.	Turbidity.	Color.	Chlorides.	Hardness.	Iron.	Micro-organisms per cc.
1928	1	14	9.0	32.9	0.07	9
1929	Trace	11	9.0	28.7	0.07	3
1930	0	9	9.3	30.8	0.06	3
1931	1	12	9.1	35.5	0.08	6
1932	Trace	9	9.4	35.1	0.07	2
Average	Trace	11	9.2	32.6	0.07	4.6

TABLE 4.— BACTERIAL CHARACTER OF FILTER EFFLUENT.

YEAR.	MEAN BACTERIA PER CC.		BACT. COLI — PER CENT. POSITIVE TESTS.		
	At 20° C.	At. 37.5° C.	In 0.1 cc.	In 1.0 cc.	In 10 cc.
1928	108*	30*	0	0	1.4*
1929	23	11	0	0	0
1930	5	3	0	0	0
1931	12	8	0	0	1.3
1932	21†	3†	0	0	7.4
Average	34	11	0	0	2.0

A small dose of chlorine is added to the filter effluent before distribution, as an extra safeguard.

Ordinarily, slow filters remove from one-quarter to one-third of the color of a water, but at Wakefield the degree of removal has been surprisingly high, as shown in Table 5.

TABLE 5.— PERCENTAGE REMOVAL OF COLOR BY FILTERS.

YEAR.	MEAN COLOR. (*Parts per Million.*)		Percentage Removed.
	Lake Water.	Filter Effluent.	
1928	24	14	42
1929	22	11	50
1930	18	9	50
1931	25	12	52
1932	19	9	53
Average	22	11	50

By December 31, 1932 a total of 7.5 in. of sand had been removed from the filters by scraping. This decrease in thickness of the sand layer has possibly slightly affected the bacterial efficiency of the filters. On the other hand, it has had no detrimental effect upon the degree of color removal, which has increased year by year.

The significant statistics of operation are summarized in Table 6.

*Including first days of operation. †Excluding one abnormal sample.

TABLE 6.— RESULTS OF OPERATION.

Year.	Quantity of Water—m.g.		Hours in Operation Daily.	Average rate Filtration. (M.g.a.d.)
	Filtered.	Other Sources.		
1928*	217.51	4.75	7.08	4.17
1929	267.83	0.00	7.42	4.48
1930	199.31	50.34	5.78	4.32
1931	261.75	1.42	7.14	4.55
1932	259.19	19.56	7.10	4.51

TABLE 6.— RESULTS OF OPERATION.

Year	Length of Run—Days	No. of Filter Runs	Sand Removed—Cu. Yd.	Average Loss of Head—(Ft.)	
				Initial	Final
1928*	63	9	60	0.2	5.9
1929	55	14	98	0.1	5.2
1930	75	10	83	0.1	5.6
1931	81	9	106	0.2	5.2
1932	42	18	126	0.3	4.8

For some unknown reason the filters clogged more frequently in 1932, especially during the first quarter of the year. In appearance and in general acceptability the product of this plant is superior to most of the surface waters, supplied to Massachusetts towns and cities.

Costs. The costs of the improvements, including engineering, were as follows:

New pumping equipment	$ 12 302
Water purification plant	104 406
Standpipe	12 855
Total (Excluding new ground water supply)	$129,563

*Part of year only—after Feb. 11th.

The significant costs of operation, exclusive of low-lift pumping are shown in Table 7.

TABLE 7.— COST OF PURIFICATION.

Year.	YEARLY COST.			PER MILLION GALLONS.		
	Operation.	Fixed Charges.	Total.	Operation.	Fixed Charges.	Total.
1928	$1 565.56	$6 432.00	$7 997.56	$7.20	$29.57	$36.77
1929	1 839.87	6 432.00	8 271.87	6.87	24.02	30.89
1930	1 726.40	6 432.00	8 158.40	8.66	32.27	40.93
1931	1 729.26	6 432.00	8 161.26	6.61	24.57	31.18
1932	1 605.76	6 432.00	8 037.76	6.21	24.80	31.01
Average	$1 693.37	$6 432.00	$8 125.37	$7.11	$27.05	$34.16

In 1932, the detailed costs of operation per million gallons were as follows:

	Cost Per Million Gallons
Chlorine	$0.16
Supervision and Laboratory	0.97
Filter attendance	0.93
Sand Handling	2.73
Heating and Lighting	0.43
Repairs	0.19
Total, without buildings and grounds	$5.41
Buildings and grounds	0.80
Total	$6.21

The following Contractors were employed on the work.

Pumping Equipment	The F. A. Mazzur Co., Inc.
Water Purification Plant	Arthur P. Rounds
Standpipe	Lancaster Iron Works, Inc.

The plant has been operated since the beginning under the direction of Morrison Merrill, Superintendent of the Wakefield Water and Sewerage Board, with the advice of Weston & Sampson, Consulting Engineers for the Board. The data in this paper are derived from the plant records and published with the consent of the Wakefield Water and Sewerage Department and Mr. Merrill, to whom the writer's acknowledgments are hereby made.

ON THE DETERMINATION OF ODORS AND TASTES IN WATER.

BY GORDON M. FAIR.*

[*Read September 21, 1933.*]

Determination of odors and tastes in water requires the use of the senses of smell and taste as measuring devices of what are essentially chemical or physico-chemical properties of water too small in magnitude to be detected by ordinary analytical procedures. To employ these measuring devices intelligently and successfully, it is obvious that we must know their means of functioning as well as their limitations. These are given by the anatomy and physiology of the organs of taste and smell, a brief summary of which may well serve as an introduction to this paper which has been written because it has seemed to the author that the anatomical and physiological aspects of the problem have as yet not been adequately appreciated, both in the development of measuring procedures and in the fixing of scale values of odor and taste intensities.

Anatomy and Physiology of the Senses of Taste and Smell.

Among the five senses ordinarily recognized, those of taste and smell, although commonly ranked below the senses of sight and hearing, are equally necessary to human welfare. The organs of taste and smell have as their first function to warn us against unfavorable environmental substances. They protect us in particular from consuming harmful foods. In addition they are linked with the secretion of digestive juices and with other digestive functions that are essential to proper nutrition.

The Sense of Taste.— The organs of taste are confined more or less to the mouth; in particular to the tongue. They are stimulated by a great variety of substances, but there are only four well-circumscribed kinds of taste: sour, salty, bitter and sweet. The many other sensations that we obtain from food may be traced to odors and to temperature, touch and chemical sensations. To produce taste a substance must be in solution and possess a sour, salty, bitter or sweet principle.

The different parts of the tongue, as shown by Parker [1], (see Fig. 1) vary in their sensitivity to the four kinds of taste, and there appears to be an independent sensory mechanism for each of them. The appreciation of acids is concentrated at the edge of the tongue, while salts affect the tip as well as the edge. A bitter taste is most noticeable after the substance causing it has passed over the root of the tongue. Sweet substances, as every child discovers for itself, are most relished when tasted with the tip of the

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tongue. The four tastes are produced by different chemical stimuli, among which the following may be recognized: acid tastes associated with hydrogen ions; salty tastes produced by chlorides, sulphates and nitrates; bitter tastes caused by alkaloids and by magnesium, calcium and ammonium

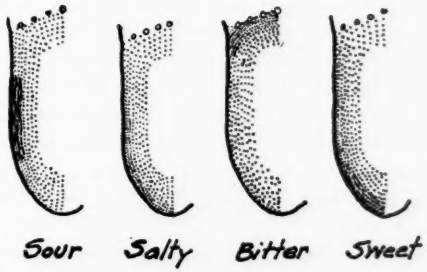

FIG. 1.—PLAN OF RIGHT HALF OF HUMAN TONGUE ILLUSTRATING THE DISTRIBUTION OF THE FOUR TASTES.

Dots represent the area and concentration of the taste: sour taste concentrated on the edge; salty taste at the tip and on the edge; bitter taste at the base; sweet taste at the tip. After Parker.

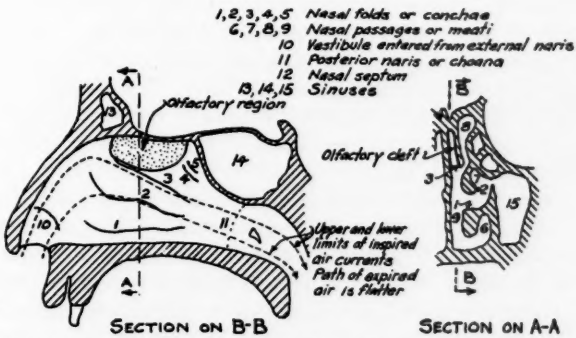
1,2,3,4,5 Nasal folds or conchae
6,7,8,9 Nasal passages or meati
10 Vestibule entered from external naris
11 Posterior naris or choana
12 Nasal septum
13,14,15 Sinuses
Olfactory region
Olfactory cleft
Upper and lower limits of inspired air currents
Path of expired air is flatter
SECTION ON B-B
SECTION ON A-A

FIG. 2.—SECTIONS THROUGH RIGHT NASAL CAVITY OF MAN SHOWING LOCATION OF THE OLFACTORY REGIONS AND NORMAL PATH OF INSPIRED AIR CURRENTS. After Parker and Paulsen.

salts; sweet tastes found in sugars, alcohols, lead acetate and saccharine and associated with hydroxyl ions.

The Sense of Smell.— There is a tendency to ascribe a "taste" to food substances as they pass through the mouth, when the true physiological response is one of "smell" reaching the olfactory organs through the passages connecting nose and mouth. These olfactory organs are situated in the highest portion of the nasal cavity, adjacent to the nasal septum (see Fig. 2). The nasal membrane, innervated by the olfactory nerve in each nasal cavity, when flattened out, is approximately square and not

far from 25 mm. to a side, or the size of two American pennies. Studies of the course taken by the currents of air through the nasal chamber during ordinary respiration show that these currents do not rise high enough to sweep past the olfactory surfaces; furthermore that their path is flatter during expiration than during inspiration. Diffusion being relatively slow, it is probable that the variations in pressure and the slight eddies accompanying quiet breathing are responsible for the gradual changes that take place in the air within the olfactory cleft and that weak stimuli produced by odors thus reaching the olfactory surfaces excite sniffing by which odorous materials are carried more effectually to the olfactory receptor and thus sensed. It is incorrect to assume, therefore, that the best way of obtaining an impression of an odor is to take a deep breath. Light sniffing which directs the air currents toward the olfactory areas will be found to be far more productive of results.

The olfactory cells in which the olfactory nerve fibers terminate carry clusters of fine hair-like lashes which are the true receptive elements of the organs of smell. In addition to the olfactory cells, free nerve endings are found in the olfactory epithelium. These appear to respond to irritants rather than true odors. Some substances, like sulphurous acid, are irritants and have no true odor; others, like the oil of vanilla, have a true odor, but are not irritating; a few, like tobacco smoke, stimulate both sets of nerves, but this may be due to the mixed character of the smoke. Irritants affect "the common chemical sense," which is not restricted to the nasal cavity but extends to all mucous membranes of the body. The so-called astringent, or chalybeate, taste associated with the salts of metals such as iron and aluminum is probably a manifestation of the common chemical sense rather than the sense of taste.

It appears to be well established that both odors and irritants are carried into the nasal chamber as material particles. The quantity required to produce sensation is almost infinitely small, yet the number of molecules involved is actually immensely large. Hermanides, as reported by Henning[2], has shown, for example, that skatol, a liquid with nauseating fecal odor, can be detected when the air contains 4×10^{-10} milligrams of this compound in one liter of air. Assuming that 50 cc. of odor-laden air are required for olfaction, it appears that 2×10^{-11} mg. of skatol produces a sensation of smell. Yet this small amount of material contains almost 10^8 molecules of skatol. Small wonder that a single gram of a number of odorous substances would be sufficient to stimulate olfaction in the entire population of the earth. Henning[2] calculates also that a sharp nose can detect the presence of a substance possessing a strong odor 100 000 times earlier than it can be found by spectrum or chemical analysis.

The particulate rather than radiant nature of odors is attested by the fact that odors do not disperse from a given center in all directions like light and sound and that they can be carried on the wind for many miles in a definite direction. Woodrow and Karpman[3], furthermore, have shown

that the time needed for an olfactory sensation to pass is directly proportional to the vapor pressure of the odorous material and hence that perception of an odor must be due to the activity of gaseous or vaporous particles. So far as the odor of a liquid or solid is concerned, it is obviously necessary for the odor-producing substance to pass into the gaseous or vaporous state in order to be smelled. The degree to which this change in state tends to take place is called "the fugacity" of the substance.

The olfactory hairs which are believed to be lipoid in character project into the mucous coating of the olfactory membrane. It follows that in order to gain entrance into the body of the hairs odorous substances must first dissolve in water and then in oil, the latter appearing to be of controlling importance.

The organs of smell are quickly fatigued. Protracted smelling of an odor exhausts the power to recognize it. Popularly this is referred to as "getting used to an odor." Breathing fresh air restores the power to recognize odors anew. Inability, or loss of ability, to respond to odors is known as "anosmia." Natural keenness of perception varies in different individuals, but it is possible to sharpen the sense of smell by practice. Although man's sense of smell is said to be less acute than that of the animals that have the power of trailing the scent of their mates or their prey, it is probably true that man reacts to a greater variety of odors; his perception of his environment is more catholic.

Qualitative and Quantitative Characteristics of Odors.

Classification of Odors.— The quality of an odor is usually designated by reference to the object from which it emanates. We speak of odors being like the smell of a violet, an onion, a piece of rubber or a pigpen. This description of odors by association stands in contrast to that of tastes, in which the terms sour, salty, bitter and sweet — possibly with the exception of the term salty,— define general qualities and have a physiological rather than a psychological basis. Our reaction to odors, furthermore, is colored by our theories of their origin. An odor that will condemn an egg might enhance the enjoyment of a cheese. This subjective view of odors makes their classification difficult and unsatisfactory. Of many general classifications, there is presented as an example that proposed by Linnaeus as modified by Zwaardemaker[4]. This classification has nine general classes, each with two or more subdivisions as follows:

1. *Etherial odors:* odors of fruits, beeswax and ethers.
2. *Aromatic odors:* odors of camphor, cloves, lavender, lemon and bitter almond.
3. *Balsamic odors:* odors of flowers, violets, vanilla and cumarin.
4. *Ambrosial odors:* odors of amber and musk.
5. *Alliaceous odors:* odors of hydrogen sulphide, hydrogen arsenide and chlorine.
6. *Empyreumatic odors:* odors of roasted coffee and benzol.
7. *Caprilic odors:* odors of cheese and rancid fat.
8. *Repulsive odors:* odors of the deadly nightshade and the bed bug.
9. *Nauseating odors:* odors of carrion and feces.

Henning[2] has attempted to set up a less associative and subjective classification which will evaluate the fundamental concepts of odor and permit designation of intermediate and mixed odors. His classification includes the following six groups.

1. *Spicy odors*, such as the odors of fennel, sassafras oil, anise and cloves.
2. *Flowery odors*, such as the odors of heliotrope, cumarin and geranium oil.
3. *Fruity odors*, such as the odors of orange, citronella, oil of bergamot and ethyl acetate.
4. *Resinous odors*, such as the odors of turpentine, Canada balsam and eucalyptus oil.
5. *Burnt odors*, such as the odors of tar and pyridine.
6. *Foul odors*, such as the odors of carbon bisulphide and hydrogen sulphide.

The classification of the quality of odors recognized for use in water analysis includes both general and associative designations as shown in Table 3.

Since olfaction is essentially a chemical process, we should look to chemical synthesis to provide us with a more scientific means of classification of odors. Much has been accomplished in determining what atoms or groups of atoms are "osmophores," *i.e.* carriers of odor. According to Henning[2], the following groups are recognized as most important: 1. aldehydes; 2. alcohols; 3. amido-compounds; 4. azimido-compounds; 5. carboxyl compounds; 6. carboxyl-ethers; 7. ethers; 8. esters; 9. hydrazines; 10. imido-compounds; 11. ketones; 12. lactones; 13. nitro-compounds; 14. nitriles and iso-nitriles; 15. phenols; 16. phenol-ethers; 17. sulphocyanates; 18. alkyl-compounds in which the methyl group is stronger than the ethyl group and in which the allyl, propyl, propenyl and amyl groups are of importance; 19. compounds including the elements antimony, arsenic, bismuth, bromine, chlorine, nitrogen, phosphorus, selenium, sulphur and tellurium.

There are numerous difficulties in the path of a satisfactory chemical classification. Among them are the following. The same osmophore produces a very different odor in one combination than in another; as in the case of methyl acetate and ethyl acetate. Very dissimilar substances may possess quite similar odors; as, for example, nitrobenzol and benzaldehyde. There is a change in odor quality as well as strength if a compound includes the same osmophore twice that appears but once in another compound; such is the case for xylol and toluol. Dilution will modify the impression produced by an odor very considerably; thus indol, which is noted for its intense fecal odor, possesses, when greatly diluted, the fragrance of orange blossoms. Certain osmophores may replace others without much change in odor as shown by the different synthetic musks. Odor mixtures may produce new types of odors on the one hand and neutralization of each other (not chemically but physiologically) on the other hand. Finally, there are almost numberless smells but only a few odor-producing groups of atoms.

The Threshold Value of Odors.— The smallest amount of an odorous

substance required to stimulate the olfactory nerves and obtain a concept of the odor is called the threshold value of the odor. Measurements of this value have been made in a number of different ways. Among them is the obvious procedure of evaporating a known weight of the odorous substance in a known volume of air and finding for what weight and volume a distinct perception of the odor can be obtained by sniffing the air. The odorometer of Allison and Katz[5] simplifies this procedure by controlling the rate of flow of an air stream over the odorous substance and diluting the resulting odor in a controlled stream of pure air until the mixture produces a detectable odor in a single inhalation. The loss in weight of the odorous substance is ascertained as well as the amount of air into which the odor has passed. Unfortunately, absolute measurements such as these are not directly applicable to water analysis.

The threshold value of an odor expressed in grams per cubic centimeter is called an "olfacty".[6] The threshold values of a number of essentials oils and certain other odoriferous substances are given in Table 1. For convenience the concentration in air of the odoriferous material is stated in thousandths of a milligram per liter. To obtain the number of

TABLE 1.— THRESHOLD VALUES OF SOME ESSENTIAL OILS AND CERTAIN OTHER ODORIFEROUS SUBSTANCES.

Substance	Concentration in Air Thousandths of a Milligram per liter	Authority
Camphor	5; 0.06; 0.016; 0.00002	1; 2; 4; 3
Chlorphenol	0.004	5
Eucalyptol	0.19	4
Hydrogen sulphide	2; 0.0001	6; 7
Heliotropin	0.1–0.05; 0.01	1; 7
Iodoform	0.027; 0.018; 0.006	8; 9; 1
Ionon (α)	0.0001; 0.00005	2; 7
Mercaptan	0.046–0.006; 0.00004	9; 5
Musk (artificial)	0.001; 0.0001; 0.00004; 0.000005	2; 8; 9; 1
Oil of clove	0.9	1
Oil of lemon	0.5–0.1; 0.13; 0.0006	1; 4; 10
Oil of orange	0.5; 0.08	1; 7
Oil of peppermint	0.6; 0.024; 0.005; 0.0007	6; 9; 1; 7
Oil of rose	0.5; 0.0002	6; 7
Oil of rosemary	0.05; 0.003	1; 7
Oil of wintergreen	0.5; 0.009	1; 7
Oil of wormwood	0.7	6
Phenol	4; 1.2	2; 7
Skatol	0.0004; 0.0000004	2; 3
Vanillin	0.0005; 0.0000002	1; 3

1. Passy; 2. Zwaardemaker; 3. Hermanides; 4. Ohma; 5. Fischer and Pentzoldt; 6. Valentin; 7. Henning; 8. Berthelot; 9. Allison and Katz; 10. Tempelaar.

molecules of the compound per cubic centimeter of air, the values presented in Table 1 must be divided by the molecular weight and multiplied by 6.06×10^{14}.

It is interesting to note from Table 1 that the threshold value of chlorphenol, one of the most objectionable odors in chlorinated water, is 300 and possibly 1 000 times smaller than that of phenol; also that the threshold values of flowery and fruity essential oils, as reported by recent workers, are extremely small. Odors produced by essential oils are associated with the growth of many of the algæ that are of common occurrence in water supplies.

The Weber-Fechner Law.— Proceeding from threshold concentrations of odors to higher intensities, we find that the increase in odor concentration necessary to cause a just perceptible increase in odor sensation, *i. e.* a threshold difference, is, within physiological limits, a definite fractional increment of the acting concentration or stimulus. This observation is in agreement with a general physiological law, known as the Weber-Fechner psychophysical law, which may be illustrated at the hand of a test for pressure sensation rather than odor sensation, as follows.

With a weight of 30 grams placed upon a finger and producing a certain pressure sensation, it is found necessary to add one gram, an increment of 1/30 or 3.3 per cent., in order to produce a just perceptible difference in sensation. With a weight of 60 grams, addition of a single gram, an increment of 1/60, or 1.7 per cent., is not perceived; it requires the same fractional increment as in the first case, namely 1/30 (3.3 per cent.), or 2 grams, to produce a just perceptible difference in sensation. In other words, the threshold difference is given by a fractional increment in weight of 1/30. If it is assumed that just perceptible differences in sensation are equal amounts of sensation, it follows that for sensation to increase by equal amounts, *i. e.* by arithmetic progression, the stimulus must be varied by a constant fractional increment, *i. e.* by geometric progression. This is the Weber-Fechner law.

The conformity of odor sensation to the Weber-Fechner law has been established by a number of different workers. Hermanides, as reported by Henning[2], found threshold differences for ethyl bisulphide, guaiacol, isoamylacetate, musk, nitrobenzol, pyridin, skatol, terpineol, and valeric acid, varying from 24 to 62 per cent. and clustered about a value of 38 per cent. for weaker as well as stronger stimulation. It follows that in the most refined observations of odor it is physiologically impossible to perceive differences in concentration of the odorous material of less than about 40 per cent., and that it is futile to attempt to attain a precision of measurement greater than this. Neither should results of measurements be reported in such a way as to imply greater accuracy.

To draw a comparison with our example of pressure sensation, the concentration of an odorous substance must be increased by 4/10 as against 1/30, therefore from 30 to 42 units as against 30 to 31, or from 60 to

84 units as against 60 to 62, in order to produce a just perceptible difference in odor sensation.

Since the odor intensity of water is reported either by a direct estimation of the odor strength on the basis of the sensation produced or by diluting a strong odor until an odor sensation is just perceptible, we must have the implications of the Weber-Fechner law clearly in mind when we try to place the determination of odor on a quantitative basis.

The Odor Scale.— With the refined measurements of Hermanides yielding threshold differences of 24 to 62 per cent. for different known substances, it is doubtful whether we should attempt to measure and express, in routine water analysis, threshold differences less than 100 per cent., or odor concentrations differing by less than 2 to 1. In suggesting this limit, the author leans upon his own laboratory observations and upon a study of results reported by Allison and Katz[5] based upon more refined measurements. In examining 21 pure odoriferous compounds, these workers observed the odor intensities and noted them much as in Standard Methods of Water Analysis[7], according to an arbitrary scale varying from 1 (very faint or detectable) to 5 (very strong). At the same time their odorometer measured the concentration of the odorous material in the air smelled. If the results of these observations are plotted, as in Figure 3, using a geometric (logarithmic) scale for odor concentration* and an arithmetic scale for intensity of sensation, we note with satisfaction the general straight-line trend of the results and the marked parallelism of the individual trends. There is indicated, therefore, first of all conformity to the Weber-Fechner law and next a relative degree of constancy in what is essentially the threshold difference for various odors as well as for various intensities of odor. If we determine the ratios of the relative concentrations recognized by Allison and Katz and expressed as recognizably different intensities numbered 1 to 5, we find that they yield an average value close to 2 to 1, *i. e.* a threshold difference of about 100 per cent. The arithmetic mean ratio for the 21 compounds is 2.3 in a range of 1.5 to 3.9; the median is 2.0. Generally speaking, the author has more faith in the median† than the arithmetic mean in dealing with problems of this kind.

Strictly speaking, the differences calculated from the data of Allison and Katz are not the minimum detectable differences in odor but differences in intensity that are recognized without resorting to great refinement. For this reason it seems to the author that they are of a magnitude that should be attainable with reasonable care and practice. If we accept the 2 to 1 ratio as the magnitude of readily attainable precision and we assign to the concentration at which an odor is just detectable, *i. e.* to the threshold concentration, a value of unity, the next higher concentration that should normally be differentiated from the threshold concentration would be 100 per cent. greater or 2, the next 100 per cent. greater or 4, the next 8,

*Allison and Katz employed an arithmetic scale in presenting their results.

†The median is that value than which half of the observations are less and half greater.

16, 32, etc. There is thus developed a rational scale of odor threshold intensities based upon the binary geometric progression 1, 2, 4, 8, 16, 32, etc.

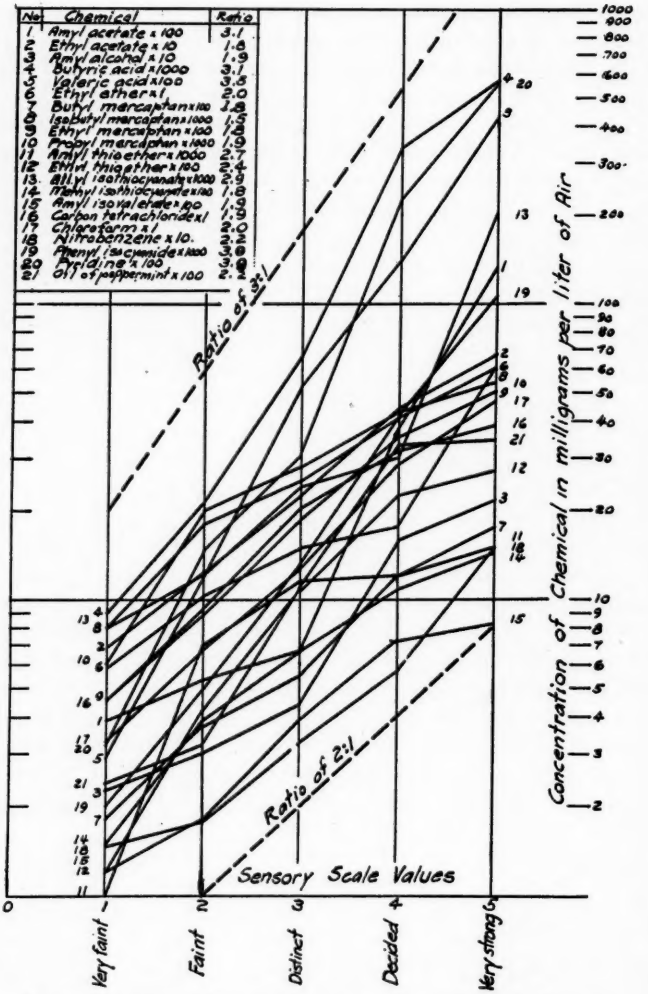
No. Chemical Ratio
1 Amyl acetate x 100 3.1
2 Ethyl acetate x 10 1.8
3 Amyl alcohol x 10 1.9
4 Butyric acid x 1000 3.1
5 Valeric acid x 100 3.5
6 Ethyl ether x 1 2.0
7 Butyl mercaptan x 100 1.8
8 Isobutyl mercaptan x 1000 1.5
9 Ethyl mercaptan x 100 1.8
10 Propyl mercaptan x 1000 1.9
11 Amyl thioether x 1000 2.7
12 Ethyl thioether x 100 2.4
13 Allyl isothiocyanate x 1000 2.9
14 Methyl isothiocyanate x 100 1.8
15 Amyl isovaleriate x 10 1.9
16 Carbon tetrachloride x 1 1.9
17 Chloroform x 1 2.0
18 Nitrobenzene x 10. 3.2
19 Phenyl isocyanide x 1000 3.0
20 Pyridine x 100 3.0
21 Oil of peppermint x 100 2.
Ratio of 3:1
Ratio of 2:1
Concentration of Chemical in milligrams per liter of Air
Sensory Scale Values
0
1
2
3
4
5
Very faint
Faint
Distinct
Decided
Very strong

FIG. 3.—THRESHOLD DIFFERENCE OF THE SENSORY SCALE VALUES MEASURED IN TERMS OF THE RATIO OF KNOWN CONCENTRATIONS OF CHEMICALS. Data from Allison and Katz.

Since this geometric series may be written as follows: $2^0 = 1$; $2^1 = 2$; $2^2 = 4$; $2^3 = 8$; $2^4 = 16$; $2^5 = 32$; etc., the idea presents itself of noting the exponent of 2 or power to which 2 must be raised rather than the magnitude

of each member of the series. The odor scale is thus established as a power or exponential scale 2^0, 2^1, 2^2, 2^3, 2^4, 2^5, etc., and the use of this exponential scale may, by analogy, with the practice of recording hydrogen ion concentration, be designated by the symbol pO*; pO 4, for example, standing for an odor threshold intensity of $2^4 = 16$. It should be noted in passing that the pO is the logarithm to the base 2 (not 10 as in the case of pH) of the odor threshold intensity or concentration. The usefulness of this rational concept of odor intensities in water work will appear in connection with the discussion of the dilution method of odor determinations.

Methods of Determining Odors and Tastes in Water.

Until recent times the procedures used by water analysts in the determination of odors and tastes in water have been only roughly quantitative. The demand for the prevention and removal of objectionable odors and tastes and the development of means for accomplishing this have stimulated interest in the problem of odor and taste measurement and have resulted in more refined procedures which are at present undergoing the test of experience.

Whatever the technique of measurement, it must be remembered in determining odor in water that an odorous substance contained in a liquid, such as water, must escape from the liquid into the air before it can be smelled. For perfect gases — and with a fair degree of accuracy for other volatile substances — the escaping tendency, or fugacity, is measured by the vapor pressure of the gas. At low concentrations of odor-producing substances, such as are generally encountered in water supplies, furthermore, the escaping tendency of a volatile substance is proportional to its concentration in the water. Hence it becomes possible to find the threshold value of such an odor either by diluting the water which contains the odorous substance or by diluting the atmosphere above the water after it has been saturated with the odor. Otherwise it would be incorrect to dilute the water. Time must naturally be allowed to elapse in either case to permit the odor in the air, or gaseous phase, to come into equilibrium with the odor in the water, or liquid phase, before testing for the odor.

The vapor pressure of any compound increases with temperature. Hence the use of the "hot odor" test. The increase is more than straight line in such a way that the temperature *vs.* vapor-pressure lines of different substances do not cross each other. At the boiling point the vapor pressure becomes one atmosphere for all compounds. Their relative vapor pressures at any temperature, therefore, are indicated by the relative magnitudes of their boiling points. The boiling points of most odoriferous substances that are encountered in water are unknown. A few values for odor-producing substances of known composition encountered in water are given in Table 2. It will be noted that the boiling points of some of the substances that give

*It should be noted, however, that as a symbol the expression pH derives from electro-metric, or potentiometric, methods of determining hydrogen-ion concentration.

trouble in water supplies are relatively high and that their vapor pressures at normal water temperatures, therefore, must be quite low.

Standard Laboratory Determination of Odor.— According to "Standard Methods"[7] the "cold odor" is observed by shaking a partly-filled bottle of

TABLE 2.— BOILING POINTS OF SOME ODOR-PRODUCING COMPOUNDS FOUND IN WATER.

Compound	Boiling Point °C.	Compound	Boiling Point °C.
Hydrogen sulphide	− 60	Cresol	+191
Chlorine	− 34	Bromphenol	+195
Mercaptan (ethyl)	+ 37	Indol	+253
Chlorphenol	+176	Skatol	+265
Phenol	+183		

the water, removing the stopper, and quickly sampling the odor given off at the mouth of the bottle. The sample of water should be at room temperature, about 20° C.

"Standard Methods"[7] prescribes that the "hot odor" be obtained by placing 150 cc. of the sample in a 500-cc. Erlenmeyer flask; covering the flask with a well-fitting watch glass; heating the water to boiling on a hot plate; removing the flask and allowing the water to cool for not more than five minutes; agitating the water by a rotary movement of the flask; slipping the watch glass to one side and quickly smelling the odor. To prevent scalding, the temperature of the vapors should not be much more than 60° C.

The quality of the odor is expressed by a descriptive epithet as in Table 3, in which are also shown abbreviations used to simplify record-keeping.

TABLE 3.— QUALITY OF ODORS IN WATER.

a — aromatic
c — cucumber
C — free chlorine, chlorinous
d — disagreeable
e — earthy
f — fishy
g — grassy
G — geranium
I — iodoform, medicinal, chlorphenol
m — moldy
mm — muskmelon
M — musty
N — nasturtium
o — oily
p — peaty
P — pigpen
s — sweetish
S — hydrogen sulphide
v — vegetable
V — violets

The sensory intensity of the odor is expressed by a numeral prefixed to the quality term. These prefixes are defined in Table 4.

According to this method of reporting odors, the combination of numeral and letter 3f indicates a *distinct fishy* odor and 2v a *faint vegetable*

odor. Combinations of odors are also encountered and may be so recorded. The expression 3v + 2m, for example, means a *distinct vegetable* and *faint moldy* odor. The reader will understand that these definitions are far from exact and that the intensities of odors that vary in quality cannot be well compared. A *faint fishy* odor, for example, because of its associations in the

TABLE 4.— SENSORY INTENSITY SCALE OF ODORS IN WATER.

Numerical Value	Term	Approximate Definition
0	None	No odor perceptible.
1	Very faint	An odor that ordinarily would not be detected by the average consumer, but that could be detected in the laboratory by an experienced observer.
2	Faint	An odor that the consumer might detect if his attention were called to it, but that would not otherwise attract attention.
3	Distinct	An odor that would be detected readily and that might cause the water to be regarded with disfavor.
4	Decided	An odor that would force itself upon the attention and that might make the water unpalatable.
5	Very strong	An odor of such intensity that the water would be absolutely unfit to drink (a term to be used only in extreme cases).

mind of the consumer will probably attract more attention than a *distinct vegetable* odor.

In order to carry the odor from the bottle or flask to the nostrils without dilution by the surrounding air, Baylis[8] has devised a glass nose piece, illustrated in Figure 4a, that covers the nostrils and is long enough to extend through the mouth of the flask to within ½ in. of the water surface. For use with 500 cc. Erlenmeyer flasks the nosepiece may be made conveniently of glass tubing about ¾ in. in diameter and 8 in. long. The end should be shaped in a flame to fit the nose of the observer. The author has designed the nosepiece or osmoscope illustrated in Figure 4b. This is inserted into the nostrils and has the advantage of directing the odor towards the olfactory cleft. This nosepiece is made more easily than that designed by Baylis and will, furthermore, fit any nose with the same nostril

distance. This distance varies for different individuals. Six measurements yield an average of 20 mm. with maximum deviation of ± 4 mm. An adjustable nosepiece is shown in Figure 4c. In using a nosepiece the observer should bear in mind that the first whiff of odor obtained by light sniffing is most important.

The odor test may be further improved by using a double flask, shown in Figure 5, to permit vigorous shaking of the water and release of the odor to the supernatant air. In accordance with Baylis'[8] suggestions the double flask is formed by uniting two 500 cc. Erlenmeyer flasks by cork stoppers and glass tubing. After filling one flask with the sample of water, the other

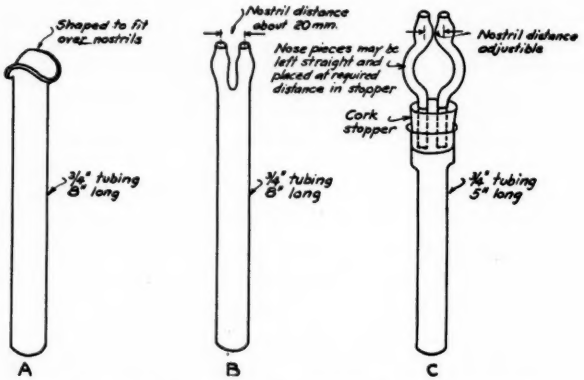

FIG. 4.—NOSEPIECES OR OSMOSCOPES THAT AID IN THE DETERMINATION OF ODORS.

flask is placed on top. The apparatus, much in the form of an hour glass, is then inverted. After the top flask has lost about half of the sample to the lower one, the apparatus is placed on its side and shaken vigorously for ten seconds or more. Placed in an upright position once again the water fills the lower flask and the odor-laden air the top one. The intensity of odor is determined with the aid of the glass nosepiece. The double flask is best modified for use in the air dilution method (discussed later) by bending the glass tubes and inserting the flasks in a stand. A mechanical shaker may also be employed to advantage.

The double-flask equipment can be used also for the "hot odor" test. Both the empty and the full flask should then be heated to about the same temperature to avoid unnecessary squirting of water from the apparatus. Baylis and his coworkers[8,9] advise that the sample be heated ordinarily to 65°–70° C. rather than to the boiling point. At the same time they state that there are certain odors, such as the odor of sulphides, that tend to disappear when the water is heated above 60° C. On the other hand, there

are other odors, such as those of sugar-beet wastes, that reach a maximum value only if the water is brought nearly to a boil.

The Water-Dilution Method of Odor Determination.— In 1931, Spaulding[10] suggested that a measurement of odor intensity be made by adding known amounts of odor-free water to the sample until the odor was just detectable. The reciprocal of the ratio of the volume of the undiluted to the diluted sample he called the threshold number, or odor intensity. A sample required to be diluted from 100 to 400 cc., for example, has a thresh-

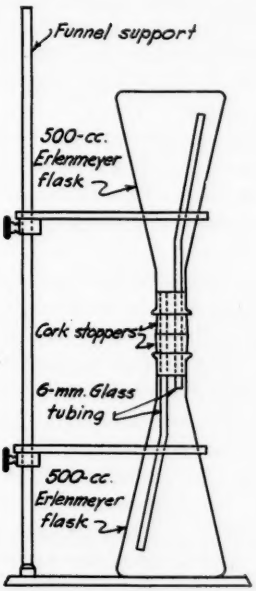

FIG. 5.—DOUBLE FLASK IN STAND FOR CAPTURING THE ODOR OF WATER.

old number, or odor intensity, of 4. Aside from preparing the necessary dilution, the procedure is otherwise the same as for the standard odor tests.

Spaulding[10] suggested preparing odor-free water by boiling distilled water in an open vessel until all traces of odor have disappeared. Ordinarily this has been accomplished when about 10 per cent. of the water has evaporated. In order to have the dilution water contain approximately the same dissolved mineral constituents as the sample to be tested, Baylis[8] prefers to prepare odor-free water by treatment of the clarified local water with activated carbon. If granular carbon is to be used, about four vertical feet of $\frac{1}{8}$- to $\frac{1}{4}$-in. material operated at a rate of one to two gallons per square foot per minute will give good results. The filter should be thoroughly

washed before being placed in service and should be kept submerged when not in use. If powdered activated carbon is to be employed, 400 to 500 p.p.m. of carbon should be added to the water, the suspension well stirred or agitated and after an hour filtered through washed filter paper or a cotton plug. The powdered carbon should be washed on a filter before being applied. Odor-free water should be stored in clean glass bottles for not more than 24 hours in a dark, cool place.

For rapid determination of the threshold number, Baylis[8] suggests that five or six dilutions should be made; but see farther on. A blank of odor-free water should also be available. Each dilution should be tested after vigorous shaking. The flasks should be scrupulously clean and should be rinsed in odor-free water before being filled with the sample and covered by watch glasses. At least one dilution should have no perceptible odor and at least two should have odors.

The general procedure for determining the hot odor is the same as for the cold odor. The dilutions, including a blank, are best heated in a water bath to insure equal temperatures for all dilutions. It is advisable to smell the blank after each dilution in order to clear the olfactory cavity of odor residuals.

Three typical threshold determinations from Baylis' laboratory[8] are given in Table 5. Baylis[8] and his coworkers express the dilution as the ratio of the volume of the sample to the volume of dilution water, obtaining the odor threshold number by adding one to the dilution water factor if it is below 100, ten if it lies between 100 and 1 000, 100 if it lies between 1 000 and 10 000, etc. If the odor threshold number is to be reported, it would seem that Spaulding's[10] suggestion of reporting the reciprocal of the threshold dilution ratio is less confusing and, as will appear, well within the precision of measurement attainable.

For purpose of discussion, the author has added to Gullan's data a column giving the dilution in terms of the nearest pO value and beneath each odor threshold number the pO value corresponding to the threshold dilution. A comparison of the results reported in Table 5 in terms of the Spaulding threshold number, the odor potential and the sensory scale of Standard Methods yields much of interest. Directing our attention first to the drinking waters we find that the sensory scale values run 1, 2, 3, 4 while the pO values run 1, 2, 4, 5 and the threshold numbers 2, 4, 15, 36. In the light of the Weber-Fechner law this indicates that the analyst of the two water samples had in mind for the sensory scale values a threshold difference close to 100 per cent. Taking the possible ratios, 23 in all, the arithmetic average is found to be 2.6 in a range of from 1.1 to 7.0; the median is 2.1. The agreement with the work of Allison and Katz[5] seems to indicate that in the binary geometric series we are dealing with a "natural" scale of odors. When the sensory scale value reported equals or exceeds the scale maximum of 5 the sensory scale apparently fails. This is not surprising. A sensory scale covering odors greater than 5 (very strong)

TABLE 5.—DETERMINATIONS OF ODOR THRESHOLD NUMBERS.
Basic data after Gullans.[9]

Dilution Ratio*	pO Value†	Sensory Scale Value	
		Cold Odor	Hot Odor
(1)	(2)	(3)	(4)
Sample 1 — Raw Water, Chicago, Ill.			
None	0	1(e+g)	2(e+g)
1:2	1	1 g	1(e+g)
1:3	1.5	0	1(e+g)
1:4	2	0	1 g
1:5	2.5	0	0
Odor threshold number	—	2	4
pO Value	—	1	2
Sample 2 — Raw Water, Whiting, Ind.			
None	0	3(m+o)	4(m+o)
1:7	3	2(m+o)	3(m+o)
1:11	3.5	1(m+o)	2(m+o)
1:15	4	1(m+o)	1(m+o)
1:17	4	0	1(m+o)
1:21	4.5	0	1(m+o)
1:31	5	0	1(m+o)
1:36	5	0	1(m+o)
1:41	5.5	0	0
Odor threshold number	—	15	36
pO Value	—	4	5
Sample 3 — Oil Refining Waste			
1:1 000**	10	5(o+S)	(5+) (o+S)
1:10 000	13.5	3(o+S)	5(o+S)
1:100 000	16.5	2(o+S)	3(o+S)
1:200 000	17.5	1(o+S)	2(o+S)
1:300 000	18	1(o+S)	2(o+S)
1:350 000	18.5	0	2(o+S)
1:500 000	19	0	1(o+S)
1:800 000	19.5	0	1(o+S)
1:900 000	20	0	1(o+S)
1:1 000 000	20	0	0
Odor threshold number	—	300 000	900 000
pO Value	—	18	20

*Ratio of sample volume to volume of sample and dilution water combined.
†pO Value corresponding to dilution ratio to nearest 0.5.
**Strictly speaking 1:1 001; 1:10 001 etc.

is probably impossible of interpretation. There is probably a tendency, furthermore, to assign the maximum value to the first dilution prepared and to scale down subsequent dilutions to meet the strength of the first. In this connection the fact should not be lost from view that the behavior of very high concentrations of odorous materials may not be in accordance with the assumption that the vapor pressure and hence the odor are proportionate to the concentration of the material. If there are visible oil films, for example, the water-dilution method if carefully carried out may yield information as to the concentration of the odor-producing substances but not necessarily as to the intensity of odor produced by them in the undiluted sample. Generally speaking, however, the solubilities in water even of oils is relatively so great in comparison with the odor-producing concentrations encountered in water analysis that the assumption of the existence of a single-phase system does not become incorrect.

By further study of samples analyzed to give the sensory scale values as well as the pO values, or threshold numbers, it may be possible to tie in the older method of reporting odors with the newer one based upon threshold dilutions. A dilution ratio of 2:1 or a threshold difference of 100 per cent. is at present indicated. A *faint* odor, therefore, seems to be produced by odor concentrations twice as great as a *very faint* one; a *distinct* odor by concentrations four times as great; a *decided* odor by concentrations eight times as great, and a *very strong* odor by concentrations 16 or more times as great. As pointed out by Gullans[9], Table 5 shows that the hot odor can be detected in dilutions two and three times as great as the cold odor. Considering this as a pO difference of one or two, we may, except in the case of low intensities, question the value of going to the trouble entailed in a determination of the hot odor by the dilution method as a routine procedure. There may be cases, however, where heating the water will bring out odor attributes not perceptible at normal temperatures.

Comparing the dilution ratios and odor threshold numbers of Table 5 with the pO values, we may note that the concept of a threshold difference which underlies the use of the pO value points a way to a reduction of the number of dilutions studied without decreasing the true precision of the dilution method. On the basis of a threshold difference of 100 per cent., the following dilutions or pairs of dilutions reported in Table 5 might have been omitted or modified.

Sample 1. Omit dilution 1:3
Replace dilution 1:5 by 1:8 (pO 3)
Saving: 1 dilution in 4.

Sample 2. Replace dilutions 1:7 and 1:11 by 1:8 (pO 3)
Replace dilutions 1:15 and 1:17 by 1:16 (pO 4)
Omit dilution 1:21
Replace dilutions 1:31 and 1:36 by 1:32 (pO 5)
Replace dilution 1:41 by 1:64 (pO 6)
Saving: 4 dilutions in 8.

Sample 3. Omit dilutions 1:200 000; 1:350 000; 1:800 000 and 1:900 000
Scale remaining dilutions to approximately
1:1 000 (pO 10); 1:8 000 (pO 13); 1:130 000 (pO 17);
1:260 000 (pO 18); 1:520 000 (pO 19) and
1:1 000 000 (pO 20).
Saving: 4 dilutions in 10.

In highly refined work it might be possible to observe pO values lying halfway between the integral numbers suggested. It should be clearly recognized, however, that there is danger of indicating fictitious accuracy of work and that the greater the dilution the greater the steps that should be left between successive dilutions. Should we be able to observe threshold differences of 50 per cent. we could distinguish between a dilution of 1:1 and 1:2, but we could not distinguish between 1:10 and 1:11, only between 1:10 and 1:15; also not between 1:100 and 1:110, only between 1:100 and 1:150; also not between 1:300 000 and 1:350 000, only between 1:300 000 and 1:450 000; also not between 1:800 000 and 1:900 000, only between 1:800 000 and 1:1 200 000 etc. If the threshold number scale is to be retained, it would appear wise, therefore, to have it conform more or less to the principles incorporated in the Weber-Fechner law. A useful scale of round numbers might include the following odor threshold numbers assuming very refined work: 0, 0.5, 1, 1.5, 2, 3, 4, 5, 6, 8, 10, 15, 20, 30, 40, 50, 60, 80, 100, 150, 200, 300, etc.; or expressed in a different way 0, 0.5, 1, 1.5, 2, 3, 4, 5, 6, 8, times 10^0, 10^1, 10^2, 10^3, 10^4, etc. For ordinary work this scale of threshold numbers would be reduced to 0, 1, 2, 4, 8 times 10^0, 10^1, 10^2, 10^3, 10^4, etc.

The Air-Dilution Method of Odor Determination.— Instead of arriving at the threshold value of odors in water by diluting the sample with odor-free water, it is possible to capture the odor of the undiluted sample in the atmosphere overlying the water and to dilute this odor with fresh air (odor free) to its threshold point. This approach has long been used by workers in fields other than water analysis. Dilution is readily accomplished in a standard gas burette, manipulation of the sample following in a general way the technique of gas analysis. If desired, the odor may be sniffed directly through the nosepieces of an osmoscope as the odor is being displaced from the burette. It may be found more satisfactory, however, to displace the odor into an osmoscope of capacity smaller than the volume of odor or air-odor mixture discharged and to draw the odor into the nostrils from the osmoscope. Mercury appears to be the most satisfactory fluid for use in the burette as it does not take odors into solution to a measurable extent or enter into combination with them. Its high density, furthermore, facilitates transfer of the odor from its original container to the burette. If the odor-producing substance is an active gas such as hydrogen sulphide or chlorine, the mercury should be freshly and thoroughly purified and well dried, and the test should be carried out as rapidly as possible. In line with what has been said about the odor scale, the procedure that will ordinarily

be found most useful calls for filling the burette with the original odor, displacement of half the sample into the osmoscope, observation of the odor, dilution of the remaining odor to twice its volume, displacement of half the resulting volume into the osmoscope, observation of the odor, and repetition of this procedure until the odor is no longer perceivable.

One drawback to the use of a standard gas burette is its limited capacity, commonly 100 cc., which reduces the amount of displaceable odor to about the lowest quantity (50 cc.) that is required for olfaction. To increase the available odor volume and simplify technique, there has been developed in the Laboratory of Sanitary Engineering at Harvard very largely from a

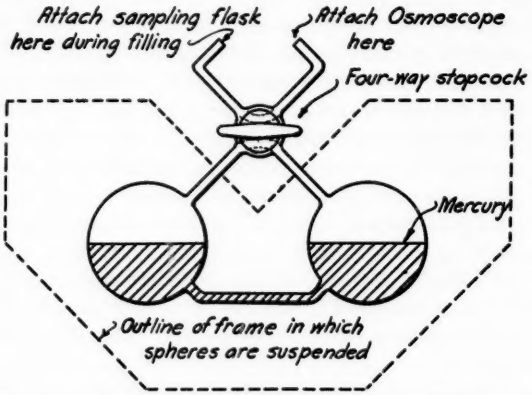
Attach sampling flask here during filling
Attach Osmoscope here
Four-way stopcock
Mercury
Outline of frame in which spheres are suspended

FIG. 6.—TWIN-SPHERE OSMOMETER FOR THE EVALUATION OF ODORS BY THE AIR-DILUTION METHOD.

design by W. F. Wells, the "twin-sphere osmometer" illustrated in Figure 6. When the apparatus is half-filled with mercury, the volume of displaceable odor is about 220 cc. This figure is reduced to about 100 cc. when progressive dilutions are being made. If the osmoscope receiving the odor is dimensioned so as to hold about 60 cc., we insure its being flushed out and filled with the odor. The twin-sphere osmometer is filled and emptied by tilting the stand in which the spheres are suspended and driving the mercury into one or the other of the spheres or permitting it to half-fill both of them. A four-way stopcock connects each sphere either with the outside or with the other sphere. Obviously only a single dilution ratio of 100 per cent. can be attained. The number of dilutions yielding an odor thus establish the pO of the sample.

Operation of the device is similar to that of the gas burette. The operating schedule may be outlined as follows: Fill the left sphere with mercury by tilting the frame left to the 45-degree position. With the four-way cock vertical connect the odor flask to the left opening and permit the odor to

displace the mercury by rotating the frame slowly right to the opposite 45-degree position. Return the stopcock and frame to the horizontal position to divide the odor equally between the two spheres. With the stopcock vertical and the osmoscope attached to the right outlet, slowly tilt the frame right to the 45-degree position to drive the odor (half the total volume) from the right sphere into the osmoscope and at the same time to introduce an equal amount of air into the left sphere, thus diluting the remaining gas 1:2. Detach the osmoscope and sniff the odor. Return stopcock and frame to the horizontal position to divide the diluted odor equally between the two spheres. Renew this displacement and dilution procedure until the threshold dilution is passed. Note the number of dilutions as the pO value or find the threshold number by raising 2 to a power equal to the number of dilutions.

Once filled with the odor to be measured, the twin-sphere osmometer permits a rapid determination of the pO value with adequate precision for most water-works requirements. The large mercury surfaces of the osmometer, however, require that careful attention be paid to the errors that are associated with odors of active gases such as hydrogen sulphide and chlorine.

Tests of the air-dilution method against the water-dilution method have yielded identical threshold numbers or pO values. Further studies are contemplated.

It should be noted in passing that odors produced by gases such as hydrogen sulphide and chlorine are subject to error in the water-dilution method as well as in the air-dilution method, if odor-free water is prepared from the local supply. The diluting water may then possess an unsatisfied chlorine demand or may contain substances capable of being reduced by hydrogen sulphide. In the presence of such gases, therefore, it may be well to employ odor-free distilled water.

Determination of Taste. Unless the hygienic safety of a water sample is known in advance, a taste test presents a hazard to the water analyst. For this reason, probably, there is no standard procedure for observing or recording the taste of water. It is doubtful, furthermore, whether the analyst wishes to determine the taste as such, for as previously stated, there is a tendency to ascribe tastes to substances passed through the mouth when the true physiological response is one of smell, the common chemical sense, touch or temperature. It is more probable that the analyst wishes to find the effect upon all the sense organs that are stimulated by water taken into the mouth.

If the sample of water is potable, a small amount of water may be taken into the mouth and its quality and intensity observed. If the odor factor is to be excluded, it may be advisable to hold the nose or refrain from sniffing during the test. Since there are threshold values of taste and of the common chemical sense as well as of odor, the water-dilution method may be employed to arrive at these values. The intensity of taste may be estimated in terms of the sensory scale or ascertained by dilution in terms of the

threshold number or the pT value. There seems to be no reason why taste sensations should not obey the Weber-Fechner Law, but the author is not at present able to give values for the threshold differences of true taste. In the case of the odor-taste effect of substances that possess both an odor and a taste, the odor effect may be found to dominate the threshold difference. A single test of the so-called chlorphenol taste yielded a pO value of 10 or 11 associated with a pT value of only 5 or 6. From this it would appear that chlorphenol like many other so-called tastes is more correctly an odor which can be detected more easily by direct olfaction than by taking the water into the mouth.

The sense of taste, like that of odor, is easily fatigued. It may be refreshed by rinsing the mouth with warm water. In order to expose the most sensitive areas of the tongue to a given taste, the observer may make judicious use of this organ in tasting, once the quality of the taste has been indicated by a first sampling. The bitter principle of the "cucumber taste" of *Synura*, for example, is most apparent when the water containing it reaches the base of the tongue.

Conclusion and Acknowledgments.

Much of the material contained in this paper is not new, and much of the discussion emanates from a re-study of data accumulated by others. It is believed, however, that it is worth while to bring the scattered material together and review it critically at the same time as a new odor scale and a new dilution method are introduced. Where there has been criticism of the work of others, it is hoped that it has been made in a constructive spirit which will further the adequate solution of the problem of quantitative determination of odors and tastes in water. Needless to say there is much in this paper that is applicable to the determination of odors in the atmosphere, a vexing problem to the sanitary engineer.

In closing, the author wishes to acknowledge the assistance and advice in developing the air-dilution method which he received from William Firth Wells, Instructor in Sanitary Science at Harvard and from Dr. Korokuro Hirose, Rockefeller Fellow at Harvard and Assistant Professor of Sanitary Engineering in the Tokyo Imperial University of Japan.

REFERENCES.

[1] Parker, G. H., 1922. Smell, Taste and Allied Senses in the Vertebrates. Philadelphia, J. B. Lippincott Co., 192 pp.

[2] Henning, Hans, 1924. Der Geruch, 2nd Ed. Leipzig, J. A. Barth, 434 pp.

[3] Woodrow, H. and Karpman, B., 1917. A New Olfactrometric Technique and Some Results. Jour. Exp. Psych., Vol. 2, pp. 431–447.

[4] Zwaardemaker, H., 1895. Die Physiologie des Geruchs. Leipzig, Wilhelm Englemann, 324 pp. Also 1925. L'Odorat. Paris, Gaston Doin, 305 pp.

[5] Allison, V. C., and Katz, S. H., 1919. An Investigation of Stenches and Odors for Industrial Purposes. Jour. Ind. and Eng. Chem, vol. 11, pp. 336–338.

[6] Zwaardemaker, H., 1926. Odoriferous Materials. International Critical Tables, vol. 1, pp. 358–361.

[7] Standard Methods for the Examination of Water and Sewage. 1933. 7th Ed. New York, American Public Health Association, pp. 11–12, 159–160.

[8] Baylis, J. R., 1932. Procedure for Making Odor and Taste Determinations. Water Works and Sewerage, vol. 79, pp. 425–426.

[9] Gullans, Oscar, 1933. Procedure for Making Odor Determinations. Jour. Am. Water Works Assn., vol. 25, pp. 974–981.

[10] Spaulding, C. H., 1931. Quantitative Determination of Odor in Water. Am. Jour. Public Health, vol. 31, pp. 1038–1039.

Discussion.

Charles H. Spaulding.* In discussing this paper, the writer would refer to the table of dilutions for odor determinations (Table 6), which is in use in the Springfield laboratories and which was proposed in an effort to avoid fictitious accuracy and unnecessary labor. In this table the odor values increase by increments which approximate twenty-five per cent. The use of this table in a series of eighty-six determinations checked by different observers verifies the author's conclusions as to the application of the Weber-Fechner law. About one-fourth of the determinations were checked exactly. Two-thirds of the determinations checked within one dilution and ninety-four per cent. checked within two dilutions. We concluded from these results that almost any two observers should be able to check within three or four dilutions; while trained observers could expect agreement within two dilutions.

In view of the ease with which this accuracy is reached, and the simplicity of the technique using Erlenmeyer flasks with loose, glass covers, the writer doubts the necessity of the refinements which have been proposed, such as glass nose-pieces, etc. If we are going to take cognizance only of pound or half-pound quantities, why should we guard against the loss of an ounce or a fraction of an ounce? The writer's experience indicates that the simplest technique is sufficient in this purely empirical determination, and that the adoption of a more refined procedure cannot be expected in laboratories which still adhere to the old method. It has seemed to the writer that we are missing a lot of valuable information relating to odor removal processes by adherence to the sensory scale of "Standard Methods," and that every effort should be made to give the water-works laboratories a simple quantitative procedure of a degree of accuracy commensurate with practical requirements in order to release the information which will put odor control in water purification on a rational basis. The analysis which the author has made of the sensory limitations and the application of the Weber-Fechner law is a step in this direction. The tendency to use special apparatus is unnecessary and a step in the wrong direction, in the writer's opinion.

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Another objection of the same kind should be made to the adoption of a logarithmic scale of odor values or any other than the threshold value expressed as the reciprocal of the dilution, because such scales do not permit the direct measurement of the efficiency of various odor removal processes. Reference to Table 5 illustrates this point. If we reduce the odor threshold number from 36 to 15 by some process, we know that we have accomplished about 60 per cent. reduction of the odor, or 21 units.

TABLE 6.— DILUTION TABLE FOR ODOR DETERMINATIONS.
WATER PURIFICATION PLANT, SPRINGFIELD, ILLINOIS.

The purpose of this table is to maintain uniformity of approximations over all ranges of values and to avoid fictitious accuracy and waste of time in attempting too close distinctions. A value recorded in any case should mean that the next higher dilution on this table was negative.

Dilution Number	Odor Value	Quantity Used, ml.	Dilution Number	Odor Value	Quantity Used, ml.
1	1.0	100	17	36	2.8
2	1.3	78	18	43	2.3
3	1.6	63	19	56	1.8
4	2.0	50	20	71	1.4
5	2.5	40	21	83	1.2
6	3.1	32	22	100	1.0
7	3.9	26	23	125	0.8
8	4.8	21	24	143	0.7
9	5.9	17	25	170	0.6
10	7.4	13.5	26	200	0.5
11	9.3	10.8	27	250	0.4
12	11.6	8.6	28	330	0.3
13	15	6.7	29	400	0.25
14	18	5.5	30	500	0.20
15	23	4.2	31	570	0.15
16	29	3.4	32	1 000	0.01

If we use the corresponding pO values, the reduction is from 5 to 4, the percentage reduction is 20 and the unit reduction is 1. Neither the percentage nor the unit reduction on the logarithmic scale gives any indication of the work which has been performed by the odor removal process. It is apparent that the adsorption of odors by carbon which would reduce the threshold number from 36 to 15 would be considerably more of a task than the reduction from 8 to 4; yet the reduction in pO units would be the same in either case.

Notwithstanding this objection, the author's remarks on the relation of the logarithmic scale to the sensory scale are interesting and instructive. In the writer's experience the numerals of the "Standard Methods" scale are approximately the exponents of the threshold numbers to the base 2 and this relation is worth remembering.

There are many other interesting observations in this paper which make it a valuable contribution to the literature of taste and odor problems.

GORDON M. FAIR. The author is in hearty agreement with Spaulding's statement to the effect that the quantitative determination of odors in water should be kept as simple as possible in order to remain within the reach and ken of water-works operators. It does seem to him, however, that the use of the nosepiece suggested by Baylis, or of the author's osmoscope, is generally worth while and that it simplifies procedure rather than complicating it. Discussion of refinements in procedure and of new apparatus is included in the author's paper not with a view to making the methods or equipment part of routine odor determinations, but in order to cover the subject as broadly and inclusively as possible both from the standpoint of the water-works operator and the laboratory investigator.

The test of the Weber-Fechner law in connection with the dilution table presented by Spaulding is interesting. It is gratifying to note in this connection that Spaulding's observation that trained workers may be expected to agree within two dilutions, each differing by about 25 per cent., lends support to the author's contention that the odor-threshold difference lies somewhere between 50 and 100 per cent., and that recognition of a difference of 100 per cent., or a ratio of 2 to 1, may reasonably be expected in routine observations. In the light of Spaulding's own statements, it seems, however, that his suggested dilution scale (Table 6) is cut too fine and that simplification of procedure, as well as of reporting, might be obtained without sacrifice of precision by omitting every second and third value in Spaulding's table and thus bringing it into substantial agreement with the author's proposed pO scale. Spaulding's experience that "the numerals of the 'Standard Methods' scale are approximately the exponents of the threshold values to the base 2" also checks the author's findings and statements which connect the sensory scale and the pO scale, or threshold numbers, and thus tie in the new with the old, as well as confirming the Weber-Fechner law.

The author cannot agree with Spaulding's remarks relative to the merits of expressing the efficiency of odor removal processes in terms of odor threshold numbers instead of pO values. Spaulding's statements are well taken, however, and offer an opportunity to supplement the discussion of the pO scale given in the body of the paper. To begin with, it is incorrect to state that a reduction in the odor threshold number from 36 (32) to 15 (16) represents an efficiency of $\frac{36-15}{36} = 60$ (50) per cent. while the reduction of the corresponding pO values from 5 to 4 represents an efficiency of $\frac{5-4}{5} = 20$ per cent. To make such a calculation is to use an arithmetic yardstick first in measuring an arithmetic difference and next in measuring a geometric difference and to be surprised that the results are not comparable. If it is clearly recognized that each pO value records a concentration of odor-producing substances twice that recorded by the next lower pO value or conversely half that recorded by the next higher pO value, it becomes obvious that a unit reduction in the pO value such as

from 5 (threshold number = 32) to 4 (threshold number = 16) is equivalent to a reduction of 50 per cent. (not 20 per cent.) in the concentration of odor-producing substances. It should be realized, furthermore, that the water consumer is not interested in the concentration of odor-producing substances but in the intensity of the odor sensation they produce. Since he can readily differentiate between odor intensities that differ by a pO value of 1, or in a concentration ratio of 2 to 1, the work accomplished by reducing the threshold number from 36 (pO 5) to 15 (pO 4) is to him exactly the same as that done in reducing the threshold number from 8 (pO 3) to 4 (pO 2), *i. e.* the physiological difference is the same. The amount of odor-removing substance required to accomplish this work is, of course, different, but an understanding of the significance of the pO scale makes the evaluation of this phase of the problem a very simple matter. Let us assume, for purpose of discussion, that it takes a unit of odor-removing substance to remove a unit concentration of odor-producing material. Using the concept of threshold numbers, it then appears that to reduce the odor in a water with odor threshold number 32 to an odor with threshold number 16, (32 - 16) = 16 units of odor-removing substance would be required, while to reduce an odor with threshold number 8 to one with threshold number 4, only (8 - 4) = 4 units, or 4/16 = ¼ of the first amount, would be required. The same answer may be conveyed in terms of the corresponding pO values by stating that since in each case the reduction is one pO unit and since pO 3 is less than pO 5 by two pO units, it requires ½ x ½ = ¼ the amount of odor-removing substance to reduce the pO value of a water from 3 to 2 that it does to reduce it from 5 to 4. Other calculations can be made with equal facility. It merely becomes necessary to adjust our thinking and procedure to the geometric scale which we are employing, and not to forget that we are adopting this geometric scale because its use is rational. If properly applied, a rational scale must give rational measurements. The reader should bear in mind, however, that Spaulding wished to point out the possible pitfalls of the geometic scale in choosing the examples presented in his discussion. The author is indebted to him for doing this.

ADVANCES IN IRON COAGULATION AND COAGULANTS.

BY E. L. BEAN.*

[*Read September 21, 1933.*]

Another definite milestone in the application of iron compounds to water purification has recently been passed. Iron has been used for many years in the treatment of alkaline and turbid waters yet, although in nature iron compounds may play a major part in the clarification of soft waters, they have been generally considered unsuited for use in treatment of such waters and, until recent years, their use has not been carefully studied.

As early as 1902, Duyk used ferric chloride at Middlekerke, Belgium, and in 1903, Bull applied ferrous sulphate and lime at Quincy, Ill. During the succeeding years the latter was introduced in many plants treating hard waters, but there were no outstanding developments until 1926 when Mohlman and Palmer demonstrated that ferrous sulphate could be economically oxidized by chlorine to form an effective coagulant. The following year Enslow and Hedgepeth made the first application of this coagulant, in water treatment, to the highly colored water at Elizabeth City, N. C., with successful results.

Since 1927, considerable interest in iron coagulants has been manifested, particularly in plants in which color removal obtained by aluminum sulphate was not satisfactory, fluctuations in quality of raw water gave unsatisfactory coagulation at times, and algæ growths and slimes clogged filters. More recently the need for removal of manganese has added impetus to iron coagulation. Experimental or operating runs have been made with ferrous sulphate and lime at Windsor, Ont.,[1] Providence, R. I.,[2] Baltimore, Md.,[3] and Lawrence, Kan.,[4] all of which have produced more satisfactory results than could be obtained with alum. Better results have, however, been recorded on soft colored waters by use of chlorinated copperas (in conjunction with lime to obtain various pH values) in plant operation of Elizabeth City, N. C.,[5] Chickasaw, Ala.,[6] Hertford, N. C.,[7] Mamaroneck, N. Y.,[8] and Providence, R. I.[9] Experimental findings have also favored this coagulant at Chicago, Ill.,[10] Monroe, La.,[11] and for a water in Pennsylvania reported by Weston.[12] Experiments at Cleveland, Ohio[13] and Chicago, Ill.[10] indicate that ferric chloride is a desirable coagulant for Great Lakes waters. At Wilmington, Calif., Wilson[14] obtained such excellent results on colored well water that two plants have been designed for treatment utilizing ferric chloride as the coagulant.

No doubt the high cost of iron compounds was, to a considerable extent, responsible for the small amount of investigation of the use of iron during the twenty-year period between the time of Whipple's report[15]

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upon the "Ferro-Chlor Process" in use at Middlekerke, Belgium, and the oxidation of ferrous sulphate by chlorine in 1926. Ferrous sulphate was the only iron compound available at a price not almost prohibitive. With the advent of chlorinated copperas the first ferric coagulant became available at reasonable cost. Since that time the price of chlorine has dropped so markedly that chlorinated copperas may now be termed a comparatively cheap coagulant. Ferric chloride prices have also been reduced materially. In 1931, Wilson[14] reported the appearance on the California market of a fifty-per cent. ferric chloride solution at "a particularly attractive price." Present ferric chloride quotations in the Midwest would have been considered very low a few years back.

Writing in January, 1933, Baylis predicted: "There will be an increasing use of iron compounds for coagulating water. The present low price of chlorine may make feasible the manufacture or home production of ferric chloride at a cost to compete with alum." Since this statement was made, an anhydrous ferric sulphate has been placed on the market in granular or powdered form. Some deliveries received at Providence have contained as high as ninety-six per cent. of $Fe_2(SO_4)_3$. This material is now being quoted at a price equivalent to the cost of chlorinated copperas, per pound of ferric iron. For the first time a pure ferric sulphate is obtainable commercially. Also for the first time an iron compound is available that may be handled, stored in bulk, and fed by dry-feed machines without undue difficulties. The new ferric sulphate ("Ferrisul," trade name) is somewhat hygroscopic, but under any ordinary atmospheric conditions serious trouble will not be experienced. This advantage will be particularly appreciated by those operators of large plants who have experienced the difficulties in handling and feeding copperas and who have calculated the labor cost attached to the methods required. It is also significant in view of the fact that dry-feed apparatus is now generally considered less subject to troubles and the feed more reliable than in other dosing devices. In this connection it might be well to note that within the past year a solution-proportioning and feed device has appeared on the market which is practical and which will no doubt produce good results in the feeding of solutions. However, most of the newer plants have been equipped with dry-feed machines, and it seems unlikely that they will be replaced. When suspended on scales good control results.

Ferric sulphate will not readily dissolve in dilute solutions; therefore provision must be made to dissolve the chemical (when discharged by dry-feed machines) under the proper conditions. This may be done readily and cheaply.

Application of Iron Salts to Alkaline Waters. In unbuffered or poorly buffered solutions, aluminum compounds form soluble aluminates on the alkaline side, the tendency toward such formation increasing with increased hydroxyl-ion concentrations. Since the iron compounds do not form soluble compounds in this alkaline range they have been generally

used in conjunction with softening processes. It has been demonstrated within recent years that in some highly mineralized and buffered waters soluble aluminates are not formed and floc dispersion does not occur up to pH values even as high as 9.2. This has resulted in certain cases changing to alum in place of ferrous-sulphate coagulant. The physical characteristics of copperas have been a major item of consideration inasmuch as bulk storage is impossible and labor costs for handling are considerable. The iron salts give very satisfactory results in all cases where the pH is high; aluminum sulphate is giving satisfactory results in a number of softening plants, but it is not always applicable. The recent appearance on the market of ferric coagulants in dry form at reasonable cost may well counteract any present trend away from iron in connection with softening processes.

Application of Iron Salts to Soft and Colored Waters. In soft waters, due to very dilute solutions and lack of buffering action, adjustments of chemical treatment are much more difficult than is the case with waters of high mineral content. For many years alum compounds have been utilized for the removal of color and turbidity from such waters, with varying degrees of success. In many cases satisfactory results were not obtainable but, until the advent of ferric-iron coagulants there was no alternative. Chlorinated copperas proved to be effective in the removal of extremely high colors at Elizabeth City[5] and since that time ferric compounds have proved effective on other waters. It is generally agreed that at low pH values (in the acid range) the iron forms a "color floc," or complex ferric-organic precipitate, through ionic neutralization of the charges on color particles. At a high pH value, true ferric hydroxide floc is produced. The complex precipitates are stated by Enslow[16] and others to have adsorption properties far superior to the true ferric hydroxide floc. This being true, color removal in most waters can be most effectively accomplished by coagulation at low pH values, as is the practice at several plants.

Pertinent to the consideration of adsorption capacities an interesting experiment is reported by Wilson[14] at Wilmington, Cal. Pure ferric hydroxide was prepared and added to highly colored raw water, after fifteen minutes agitation the water was filtered, the filtrate being perfectly colorless. The hydroxide sludge was then used again with equally good results. Re-use of the sludge was repeated eleven times with success.

Since ferrous compounds will not be oxidized except at very high pH values, they are not generally suitable for use where color removal is the major objective, except when converted to the ferric form by chlorination. As has been reported by McCrea,[17] oxidation or decomposition of organic materials by use of chlorine or permanganate is sometimes necessary as a part of ferric coagulation. Waters which require such treatment contain iron compounds and organic matter in complex combinations.

When treating certain waters in contact-bed processes it is necessary that the degree of aëration be controlled. In a process involving coagula-

tion and precipitation the greater the degree of oxidation obtained the better, whether produced by aëration, chlorination, permanganate treatment, or other means. If aëration or other treatment is effective in oxidizing the natural coagulants to the highest or tri-valent form, coagulation of these will take place, thereby reducing the quantity of coagulant dosage necessary. On the other hand, if these minerals are not completely oxidized by the preliminary treatment, they will not pass the filters, provided sufficient mixing and retention are available, unless the concentration of unoxidized minerals is too great in proportion to the total concentration of coagulant present. The ferric ion in the applied dose will react toward these lower mineral forms somewhat in the nature of a catalyst. If caustic substances are used to produce adequate hydroxyl-ion concentration (pH of not less than 9.0) during a proper period of time the natural coagulants in many waters will be oxidized without aëration or other treatment. Waters which fluctuate in character are almost certain to demand special oxidation treatment at some time.

In conjunction with iron coagulation, manganese removal is readily accomplished. At Providence continuous and complete manganese removal has been secured for the past two years. A pH of about 9.6 is produced by lime treatment following coagulant dosing. In some cases it is no doubt possible to coagulate at a low pH, thereby securing the maximum decolorization by molecular adsorption of the "color floc," and later to raise the pH at some point previous to filtration. In such processes manganese is, in general, oxidized, coagulated, and precipitated in the same way as iron. Manganese cannot be removed by iron coagulation at low pH values.

Since alum coagulates best (in soft waters) in the neutral or slightly acid range, it would be expected that at least partial removal of alumina would take place when iron coagulation is carried out in this range. Soluble aluminates are ordinarily formed in the alkaline range, therefore no removal of alumina would be expected with coagulation at pH 9.6. At Providence, no removal of alumina resulted with ferrous sulphate and lime coagulation; but with chlorination of the copperas, at the same pH, alumina was reduced from 0.33 p.p.m. in the raw water to 0.13 p.p.m. in the filtered water; approximately sixty per cent. removal.

Adjustment of hydrogen-ion or hydroxyl-ion concentrations for proper iron coagulation must be made according to the work which is to be performed. Ferric iron will coagulate in acid solution or in alkaline solution. At the acid end of the range is the maximum color removal which has been reported by Enslow[16] for a highly colored swamp water; as low as pH 3.8. At the other, or alkaline, end of the range is manganese removal which takes place satisfactorily at pH values above 9.0 as reported by Hopkins at Baltimore, Md., and experienced at Providence. Certain of the soft waters require treatment to a pH value in excess of this to stop red water troubles in the distribution system.

Complete prevention of corrosion of mains seems to be impossible,

but it is now generally agreed that corrosion is at a minimum when the carbonate saturation point has been reached. This may be determined by the von Heyer test. In some waters this point corresponds to a pH of about 9.6. Raising the pH value of water during the coagulation period, therefore, not only will remove manganese but also produce a less corrosive effluent. Such treatment also allows time for completion of chemical reactions before filtration and produces a stable effluent, one not only low in corrosive power but also free from precipitable material. Mention should be made of the fact that, as attested by recent writings of several authorities, the calcium compounds are more effective than are the sodium compounds in the treatment of very soft water for prevention of corrosion.

If pH adjustment is made by the use of lime before filtration, for the removal of manganese, or for correction of corrosive qualities, increased hardness will result. However, at Providence the hardness is only 10 p.p.m. above that produced by alum coagulation with final correction to the same pH value. Sodium compounds would not produce increased hardness but the work of Miller[18] and Bartow[19] has demonstrated that calcium compounds are more effective in iron coagulation. As previously mentioned, they are also more effective in the control of corrosion.

The two greatest factors affecting sand incrustation are degree of salt concentration and degree of oxidation. When iron coagulation is carried out in the acid or neutral range, there is no problem of salt concentration causing incrustation, but when a higher pH is maintained this problem presents itself. Hoover has stated regarding softening processes: "It should be possible to operate filters filtering water carbonated to pH 9.2 to 9.4 for from 12 to 15 years before it becomes necessary to replace the sand or other filter medium." Certainly the ferric-lime treated soft water in a properly designed plant should give no more trouble from salt concentration than the waters of which Hoover speaks. Total salt concentration produced in the ferric-lime treated water at Providence does not exceed two grains per gallon. After two years of operation with iron coagulants the sand shows no appreciable coating. It seems that there is little danger of rapid development of trouble in filter sand due to incrustation by carbonates.

Complete clarification of some waters is possible only after complete oxidation of the materials present. In other cases fair clarification is accomplished, but organic, iron, and manganese compounds are so bound up in the floc as to produce good cementing materials in the sand. Sand shrinkage, clogging and cracking may usually be traced to the presence of these materials. The zones of anaërobic decomposition reported by Janzig and Montank[20] and the so-called "acid zones" found elsewhere in filter beds, resulting in re-solution of previously deposited materials, are made possible by accumulation of organic compounds. The value of complete oxidation of all materials present in raw water is beginning to be appreciated; it cannot be too strongly stressed. In some cases this is accomplished by

aëration alone, in others by permanganate treatment, but in many more by chlorination, alone or in conjunction with aëration.

Adaptability of Ferric Iron Coagulants. Ferric coagulation is more adaptable than any other single type of treatment advised to date. The literature shows that it can be applied over a pH range from 3.8 to 10 or higher. Bartow[19] has shown that under specific conditions there is a mid-zone in which coagulation is slow. This is true for the water at Providence, but, due to the individuality of waters caused by presence of dissolved salts, other waters may have optimum pH values within this same range, as is the case with one water reported by Ventre[11] having optimum coagulation at pH 8.5. As is true of any other process, ferric coagulation should be adjusted to the needs of the water upon which it is used and to the end which it is desired to accomplish.

The times required for ferric conditioning, floc formation and precipitation have all been found to be shorter than with alum coagulation under various conditions. These facts make ferric coagulation adaptable to existing plants and point toward economy in new structures.

Ferric chloride has been gaining prominence in studies of the treatment of water as well as of sewage. It may well hold the foreground in the treatment of sewage and sewage sludge. In the field of water purification, it appears likely that ferric sulphate may be more desirable as well as cheaper. In 1925, Miller[21] proved that optimum conditions for ferric floc formation required the presence of an anion of strong coagulating power, such as the sulphate ion. He also found that with ferric chloride in partially alkalinized solutions there is a strong tendency to form colloidal suspensions and that the insoluble material formed is easily dispersed. Judd and Sorum[22] show that ferric oxide sols are more easily coagulated when free from chloride ions. Miller[18] and Bartow[19] indicate that the sulphate ions produce a broader zone of optimum coagulation. Do these facts not suggest that the sulphate salt may be more adaptable than the chloride salts in the case of tri-valent iron as is the case with tri-valent aluminum?

Conclusion. Recent studies reported in the literature indicate marked advances in the knowledge of water treatment, not the least important item being a recognition of the individuality of various waters and the need for study and adaptation of treatment methods to the individual water. Broader technical knowledge of the reactions involved and the commercial production of such a widely adaptable coagulant as ferric sulphate place before Sanitary Chemists a maze of possibilities, and impose upon them the task of determining the treatment to which a particular water shall be subjected to obtain the most desirable results from the hygienic, esthetic, and economic standpoints.

REFERENCES.

[1] Keith, *Jour. A.W.W.A.*, Vol. 21, 1929, p. 1629.
[2] Craig, Bean, and Sawyer, *Jour. A.W.W.A.*, Vol. 24, 1932, p. 1762.
[3] Hopkins, Water Purification Control, Williams and Wilkins Co., p. 22.
[4] Hough, *Jour. A.W.W.A.*, Vol. 25, 1933, p. 260.
[5] Hedgepeth and Olsen, *Jour. A.W.W.A.*, Vol. 20, 1928, p. 467.
[6] Decker, *Water Works and Sewerage*, Vol. 77, 1930, p. 255.
[7] Luther, *Jour. A.W.W.A.*, Vol. 23, 1931, p. 1159.
[8] Potter and Klein, *Jour. A.W.W.A.*, Vol. 23, 1931, p. 719.
[9] Craig and Bean, *Water Works and Sewerage*, Vol. 79, 1932, p. 301.
[10] Reynolds and Gorman, *Jour. A.W.W.A.*, Vol. 24, 1932, p. 965.
[11] Ventre, *Jour. A.W.W.A.*, Vol. 24, 1932, p. 733.
[12] Weston, *Jour. A.W.W.A.*, Vol. 24, 1932, pp. 1349–51.
[13] Lawrence, *Jour. A.W.W.A.*, Vol. 23, 1931, p. 896.
[14] Wilson, *Jour. A.W.W.A.*, Vol. 23, 1931, p. 689.
[15] Whipple, G. C., Proc. 26th Meeting A.W.W.A., 1906.
[16] Enslow, *Municipal News and Water Works*, Vol. 76, 1929, p. 227.
[17] McCrea, *Jour. A.W.W.A.*, Vol. 25, 1933, p. 931.
[18] Miller, *U. S. Public Health Reports*, Reprint No. 1028.
[19] Bartow, Black, and Sansbury, *Jour. Ind. and Eng. Chem.*, Vol. 25, 1933, p. 898.
[20] Janzig and Montank, *Jour. A.W.W.A.*, Vol. 21, 1929, p. 1319.
[21] Miller, *U. S. Public Health Reports*, Reprint No. 1023.
[22] Judd and Sorum, *Jour. Amer. Chem. Soc.*, Vol. 52, 1930, p. 2598.

MANGANESE IN IMPOUNDED WATER SUPPLIES.

DISCUSSION OF PAPER BY R. S. WESTON AND A. E. GRIFFIN.

This JOURNAL, Vol. 47, No. 1, March, 1933, p. 40.

EDWARD S. HOPKINS.*

[*Received August 1, 1933.*]

It is believed that manganese is more frequently present and the cause of trouble in water supplies than is commonly realized. An amount of 0.2 p.p.m. will produce stains upon clothes and 0.1 p.p.m., in the form of unstable colloidal oxides, will give a false orthotolidine color-test for residual chlorine. Manganese in excessive amounts is a seasonal phenomenon in the Gunpowder River water used as the supply for Baltimore, Md. The greatest concentration for any one day at the Montebello Filtration plant was 1.67 p.p.m. with a daily average of 0.48 p.p.m. for this period each year, namely September to December.

It was demonstrated by the writer in 1927[2] that the false orthotolidine color produced by manganese was caused by colloidal hydrated oxide particles. It is a well-known fact that the element is easily oxidized, and it is believed to exist in natural waters either as the flocculated hydrated Mn_3O_4 or the colloidal hydrated Mn_2O_3. The colloidal oxide is very unstable with easily displaced oxygen atoms condensed upon the surface. The ability of an oxide to adsorb excess oxygen at its surface has been generally established. It is these unstable oxygen atoms that are reduced by the orthotolidine reagent. As shown in Figure 1, taken from the writer's paper of 1927, there is no relation between the total manganese present and the amount capable of producing the color. It is to be noted, however, that with decreasing concentrations the entire amount appears to be in the colloidal condition. The danger of mistaking color from manganese for actual residual chlorine in the control of water-plant operation was pointed out. Actual occurrences of this type were later found by Forman[1] in his study of plant operation in New Jersey. Comparison of the manganese content of the Wanaque and Loch Raven reservoirs show similar characteristics. In independent studies conducted about the same period by Weston[5] at Wanaque and by the writer[3] at Loch Raven, conclusive evidence has been obtained that the manganese is dissolved by the carbon dioxide produced by anaërobic fermentation of the organic material at the bottom of these unstripped reservoirs. This fermentation is quite active at temperatures above 20° C. and is accompanied by a gradual reduction in dissolved oxygen with increased liberation of carbon dioxide. An increase in the dissolved $MnCO_3$ occurs after about 30 days at this temperature

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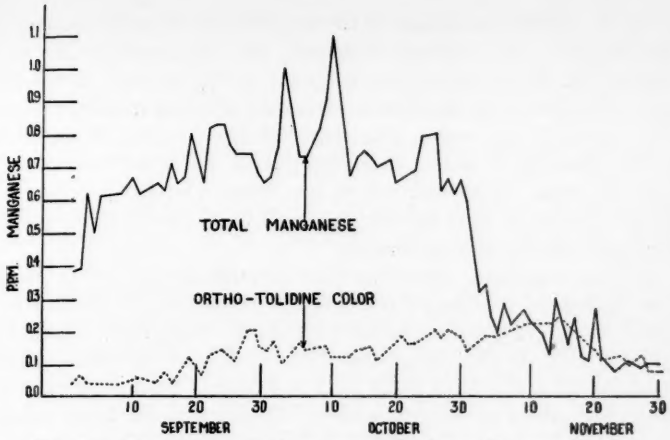

FIG. 1. — MANGANESE AND ORTHO-TOLIDINE COLOR, BALTIMORE, MD.

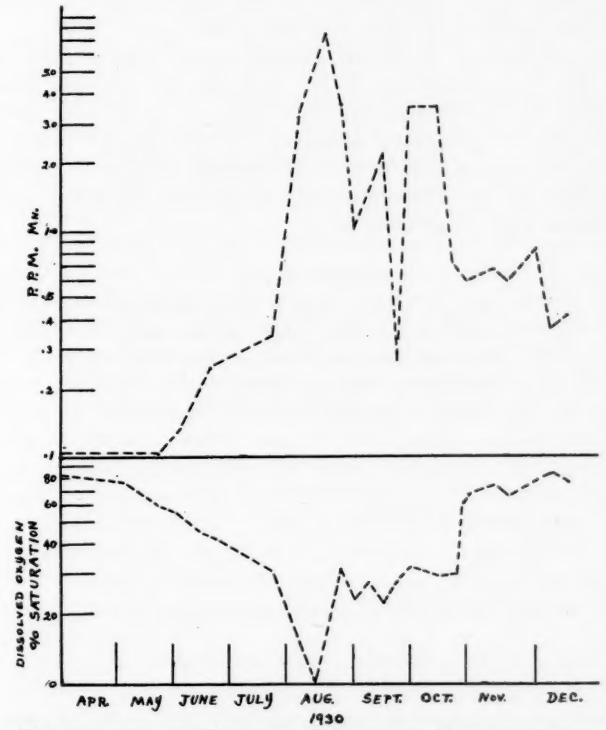

FIG. 2. — RELATION BETWEEN MANGANESE CONTENT AND DISSOLVED OXYGEN SATURATION IN THE BOTTOM WATERS OF LOCH RAVEN RESERVOIR, BALTIMORE, MD.

(see Fig. 2). With equalization of the top and bottom water temperatures in the autumn, or "seasonal overturn," the manganese is distributed throughout the water and is then converted to the hydrated oxides by the dissolved oxygen. The manganous carbonate probably quickly oxidizes to the flocculated Mn_3O_4 and is then slowly changed to the colloidal Mn_2O_3 thereby explaining its failure to readily precipitate when compared with similar iron salts. Data obtained on the Gunpowder River indicate that with the passage of time fermentation will be checked by silting of the bottom thereby eliminating troubles.

There is a growing conviction that the manganese found in the muck on the bottom of unstripped reservoirs is not necessarily related to the presence of ore in the foundation rock since manganese is widely distributed in soils. It was demonstrated some years ago by McHargue[4] that this element is a necessary plant food and occurs "in the leaves and the pericarp and germs of seeds of plants." Considering the large volume of organic material remaining in the Baltimore reservoir the presence of manganese as a residual decomposition product is to be expected. Experiments in progress at various points on the Gunpowder River should in the near future confirm or reject this hypothesis.

The precipitation of soluble manganese by alkaline water at pH value of 9.0 is to be expected and is a chemical phenomenon. Complete precipitation of the hydrated Mn_3O_4 is obtained under these conditions. The presence of fungus growth or bacteria in pipe coatings, would supplement the total manganese present by causing solution of manganese, resulting from biological processes, with subsequent deposition upon coming in contact with the alkaline water.

REFERENCES.

[1] Forman. *Jour. A.W.W.A.*, *21*, 1212, (1929).
[2] Hopkins. Ind. Eng. Chem., *19*, 744, (1927).
[3] Hopkins. Ind. Eng. Chem., *24*, 106, (1932).
[4] McHargue. Ind. Eng. Chem., *18*, 172, (1926).
[5] Weston. *Jour. A.W.W.A.*, *23*, 1272, (1931).

PIPE LININGS AND FRICTION COEFFICIENTS.

BY ELSON T. KILLAM.*

[*Read September 30, 1933.*]

In all water systems where tuberculation of pipe lines occurs, the interrelated questions of friction coefficients and pipe linings are of major importance.

Salient objectives in the improvement of standards of water-works practice have involved, and will continue to involve, consideration of the following important factors: economy; improved quality of supply; greater permanence of supply lines and distribution systems both in regard to structural life and the maintaining of carrying capacity; improved fire service; reduction in number of breaks; and reduction of leakage.

Improved methods of pipe manufacture, and the development of new methods and of new materials for providing a smooth and permanent lining, offer an opportunity for advancement in all of these important objectives. Continued effort in this direction, coupled with widespread adoption of such materials and methods, will effect as marked an improvement in the efficiency and economy of water-works supply lines and distribution systems, as has been effected in the field of water purification by filtration, chlorination and other outstanding developments.

Advantages Obtained by Provision of Permanent Smooth Lining for Pipe. The advantages of utilization of pipe with a permanent smooth lining include the following: (*a*) pipe of smaller diameter can be used for a given capacity, with consequent saving in construction cost; (*b*) the high initial capacity is maintained in the future, at which time the greatest capacity is needed; (*c*) variations in residual pressure under heavy draught, and progressive increases in pumping head, due to tuberculation, will be practically eliminated, with consequent improvement in economy and efficiency in operation; (*d*) by eliminating the uncertainty involved in the effects of tuberculation, more accurate and efficient design becomes possible; (*e*) necessity for flushing and the difficulties arising from this operation are minimized; (*f*) the necessity for disturbing improved pavement is reduced.

The Friction Coefficient as a Direct Measure of Relative Pipe Capacity. Use of the Williams-Hazen coefficient of friction is the most widely used method of definitely measuring and comparing the condition of pipe interiors, and translating this condition into terms of friction head and carrying capacity.

This coefficient, designated by the letter "c" in the formula $v = cr^{0.63} s^{0.54}\ 0.001^{-0.04}$, is a direct measure of capacity. With a constant diameter and a constant head loss, the rate of flow through a pipe line is directly

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TABLE 1.— TYPICAL VALUES OF
With Different Types and Condition of Pipe

Location of Tests.	Date of Tests.	Authority.	Reference.	Type of Pipe.	Interior Surface.
					UNLINED CAST
Hartford, Conn.	1916 or before	Caleb Mills Saville	This JOURNAL, Mar. 1916	Cast Iron	Unlined
Springfield, O.[18]	....	Laurence C. Hough	This JOURNAL, Mar. 1927	Cast Iron	Unlined
Baltimore, Md.[19]	....	Laurence C. Hough	This JOURNAL, Mar. 1927	Cast Iron	Unlined
Brookline, Mass.	1891	F. F. Forbes	This JOURNAL, June, 1892	Cast Iron	Unlined
					CEMENT LINED
Charleston, S. C.	1922	James E. Gibson	This JOURNAL, Mar. 1926	Cast Iron	3/16" Rosendale Cement[4]
	1922	James E. Gibson	This JOURNAL, Mar. 1926	Cast Iron	1/4" Rosendale Cement[4]
	1923	James E. Gibson	This JOURNAL, Mar. 1926	Cast Iron	1/4" Rosendale Cement
	1924	James E. Gibson	This JOURNAL, Mar. 1926	Cast Iron	1/16" Portland Cement[7]
					BITUMASTIC LINED
Parsippany, N.J.	1932	Elson T. Killam	This JOURNAL, Oct. 1932	Cast Iron	3/32" Centrifugally Applied Bitumastic Enamel
Weston, Mass.	1932	Chas. W. Sherman	This JOURNAL, Feb. 1933	Cast Iron	Centrifugally Applied Bitumastic Enamel
Panther Valley, Tamaque, Pa.	1933	Gannett, Seelye & Fleming	Report	Steel	3/32" Centrifugally Applied Bitumastic Enamel
					PRECAST REINFORCED
Tulsa, Okla.	1925	Fred C. Scobey	ENR May 28, 1925	Precast Reinforced Concrete	.....
Tulsa, Okla.	1925	Fred C. Scobey	ENR May 28, 1925	Precast Reinforced Concrete	.....
Tulsa, Okla.	1925	Fred C. Scobey	ENR May 28, 1925	Precast Reinforced Concrete	.....
Denver, Colo.	1925	Fred C. Scobey	ENR Apr. 29, 1926	Precast Reinforced Concrete	.....
Various Projects	....	Fred C. Scobey[15]	This JOURNAL, Sept. 1924	Precast Reinforced Concrete	.....
					SERVICE PIPE OF
Cambridge, Mass.	1927–30	G. M. Fair, M. C. Whipple and C. Y. Hsiao	This JOURNAL, Dec. 1930	Copper	Unlined
				Red Brass	Unlined
				Admiralty Metal	Unlined
				Galvanized Steel	Unlined
				Galvanized Wrought Iron	Unlined
				Steel	Unlined
				Wrought Iron	Unlined

[1] In West Hartford.
[2] Net diameter after lining.
[3] Average of 6 tests. Velocities 1.2 to 4.45 ft. per sec.
[4] Not centrifugally applied.
[5] Average of 4 tests. Velocities .89 to 2.01 ft. per sec.
[6] Average of 7 tests. Velocities .89 to 2.44 ft. per sec.
[7] Centrifugally applied.
[8] Average of 5 tests. Velocities 2.46 to 5.61 ft. per sec.
[9] Average results test 1 hr. 16 min. duration. Velocities from 6.84 to 7.35 ft. per sec.
[10] Average results test 1 hr. duration. Velocities in 10 in.—4.20 to 6.27 ft. per sec.; in 12 in.—2.91 to 4.32 ft. per sec. All tests were field tests and friction losses include loss for tees, bends and valves.

Hazen-Williams Coefficient
Interior as Determined by Hydraulic Tests.

Length of Test Section—Feet.	Pipe Diameter —Inches.	Age at Time of Test—Years.	Value of H. & W. Coeff. "C".	Test Methods.
IRON PIPE				
670	4	57	37	Quantity measured by meters tested before and after.
962	4	58	32	
1 280	6	41	52[1]	Friction measured by 6-in. Crosby test gages calibrated before and after friction tests.
1 126	6	13	60	
1 200	6	18	70	
Not Stated	24	44	116	Not stated.
		20 to 40	120	Not stated.
Not Stated	Not Stated	20 to 40	44–70	Not stated.
13 350	16	18	103–132	Quantity by pump displacement. Head by pressure gages.
CAST IRON PIPE				
500	5⅝[2]	New	137[3]	Quantity by 4-in. Crest meter. Head by mercury manometer.
500	15½	New	135[5]	Quantity by pitot tubes. Head by mercury manometer.
500	15½	New	128[6]	Quantity by pitot tubes. Head by mercury manometer.
250	5⅞	New	144.5[8]	Quantity by disc meter. Head by mercury manometer.
CAST IRON PIPE				
5 271	12	New	148[9]	
5 490	12	New	151.9[10]	Quantity by displacement in 60-ft. diameter concrete reservoir. Head by calibrated test gages.
2 857	10			
9 407	10	New	149.3[10]	
5 490	12		150.0[10]	Quantity checked by hydrant pitot.
12 263	10	New		Checked line bench levels between stations.
2.340	11.71[2]	1½	167[11]	Quantity by hydrant pitot. Head by gages.
50 000	30[12]	New	130.8–145.8	Quantity by Venturi meter. Head by gages.
CONCRETE PIPE.				
80 898	60	New	152.4[13]	Quantity by Venturi meter and color-velocity.
34 788	60	New	145.4[13]	Head by mercury manometer and water column.
21 047	54	New	152.1[13]	
38 274	54	1–4	146[14]	Quantity by Pitot tube. Head by mercury manometer.
.....	31–216	....	142–155[16]	Not stated.

VARIOUS MATERIALS.

		H. & W. Coeff.		Col. "X" M Cu. Ft.	
		New	Old[17]		
80	1½	135	135	916	Quantity by weighing tanks, and disc meters.
80	1½	136	133	908	Head loss by differential mercury manometer.
80	1½	135	129	901	
80	1½	132	126	941	
80	1½	128	127	929	
80	1½	135	38	465	
80	1½	127	37	493	

[1] Average Coefficient using actual diameter. Coefficient using nominal diameter equals 158.
[2] Actual diameter. Diameter before lining 30¼ in.
[3] Velocities from 2.25 to 2.63 ft. per sec. Conduit running full and under pressure. Correction made for line leakage.
[4] Conduit full and under pressure. Velocity 2.58 ft. per sec.
[5] In paper by F. F. Longley.
[6] Best workmanship steel forms smooth joints.
[7] This column shows coefficients after service pipe has passed quantities of water (thousands of cubic feet) given in Column "X".
[8] Hard water.
[9] Soft water.

proportional to the value of this coefficient. In other words, a smooth lined pipe with a coefficient of 150, will deliver 50 per cent. more water in a given time than a pipe with a moderate degree of tuberculation having a coefficient of 100. Likewise, the pipe with a smooth lining and a coefficient of 150 will deliver three times as much water as a badly tuberculated pipe having a coefficient of 50.

Typical Coefficient Values. Typical coefficient values determined by actual hydraulic tests on pipe lines of various materials, both without lining and with lining of cement and bitumastic enamel, are shown in Tables 1 and 2.

TABLE 2.— REPRESENTATIVE COEFFICIENT VALUES FOR PIPE WITH VARIOUS INTERIOR SURFACES.

Type of Pipe and Interior Surface Condition	Coefficient "c"
New cast iron (pit cast)	120–130
New cast iron (centrifugally cast)	125–135
Cement lining applied by hand	125–135
Cement lining centrifugally applied	140–145
Bitumastic lining, hand brushed	135–145
Bitumastic lining, centrifugally applied	150–160
Concrete with best workmanship and large diameters	145–155
Concrete, medium quality of workmanship	130–145
Ordinary tar-dipped cast iron, 20 years of service, with hard or inactive water	110–125
Ordinary tar-dipped cast iron, average effect of tuberculation:	
New	130
Age 5 years	120
Age 10 years	110
Age 15 years	105
Age 20 years	95
Age 30 years	85
Age 40 years	80
Ordinary tar-dipped cast iron, with active water causing severe tuberculation, long service	30–40

Lack of Reports of Periodic Tests to Determine Change in Friction Coefficients in Actual Water Supply Systems. A year ago the writer had occasion to make a careful search of this JOURNAL for reports upon the results of tests to determine the friction coefficient of pipe of various diameters and with various conditions of interior surface. In view of the importance of this subject, it is to be regretted that there are less than ten such reports since the JOURNAL was first published.

The periodic determination of the coefficient of discharge of pipe lines in actual service becomes of particular interest with the extended range in coefficient values made possible by the perfection of centrifugal methods of applying pipe linings. The matter is of such economic importance that it would be most desirable for a committee to undertake the compilation of data from time to time on selected typical pipe lines, in order to build up a

record of this nature. With the facilities available to various members of this Association, a representative number of typical installations could be selected. A report upon this matter, having the scope of the notable report upon the yield of drainage areas published in 1914, would form an extremely valuable addition to the records of the Association. In this connection it is pertinent to mention two papers in the JOURNAL which provide extensive data upon two specific classes of pipe, namely a "Summary of Tests Upon Concrete Pipe," compiled by F. C. Scobey, and published in a paper by Francis F. Longley in this JOURNAL, September, 1924, and a notable paper by G. M. Fair, M. C. Whipple, and C. Y. Hsiao, on "Hydraulic Service Characteristics of Small Metallic Pipes," published in this JOURNAL, December, 1930. Scobey's paper originally appeared in Bulletin 852, Bureau of Public Roads.

Essential Considerations in Obtaining Satisfactory Tests Results. In order to obtain satisfactory results from hydraulic tests to determine friction coefficients, careful consideration must be given to the following points: (*a*) it is essential to select a strategically located section of line for the test, in order that the hydraulic conditions occurring during the test may be favorable for the various measurements; (*b*) it is essential to plan the test in advance in the office before undertaking the field test, in order to make certain that adequate rates of flow can be developed and to make sure that the hydraulic gradients will lie within a suitable measuring range for whatever device may be selected for measuring pressures; (*c*) it is desirable to create as high a total loss of head as possible, and to utilize as great a length of pipe line as possible, in order to reduce the effect of instrument and observational errors (the development of high rates of flow may obviously entail considerable difficulty in discharging the water when the pipe is of large diameter); (*d*) it is essential to determine in advance of the test, all basic data such as the distance between stations and the relative elevation at gages, in order that test results may be computed on the ground during the test. By so doing, any unusual condition will at once be evident and can be corrected before the completion of the test.

It is earnestly hoped that those who are able, will conduct tests on selected lines which in all probability will be available for a number of years in the future without a change in basic conditions, in order that progressive records of friction coefficients with various pipe surfaces, may be obtained.

Discussion.

Alexander Potter.* In reading Mr. Killam's paper, several matters of interest occurred to me worthy of consideration. The first of these is in connection with the pipe lining used on the Parsippany-Troy Hills, N. J., water-supply distribution system, upon which Mr. Killam made some very interesting determinations of friction losses.

The contract for this work was let in the fall of 1931, the entire work to be constructed in the spring of 1932. In preparing the admixture for this lining, the manufacturers prepared the coating fluxed for winter use. Because of the financial stringency, a portion of the work including two miles of the 25 miles in the entire system was not completed and is yet to be laid. Though provisions had been made, before the delivery of the pipe, to have it white-washed as a protection against the sun, no attempt was made during the spring and summer of 1932 and 1933, when all work had been suspended, to keep such pipe not yet laid white-washed or otherwise protected. As a result, a very large per cent. of the pipes thus exposed began to blister and crack to such an extent that very little of the pipe could be salvaged without retreatment.

It is interesting to note that just at the time this pipe was being delivered, the manufacturers were experimenting with some modification in the manufacturing process of their coating that would make lined pipe immune to any fluctuations in temperature likely to occur under field conditions. The manufacturers state that to obtain this result they made no change in the chemical constituents of their material, but by some process which they do not care to disclose, they were able to remove the conditions which cause the softening or sagging of the materials from the walls of the pipe at high temperature, and the cracking of the coating by contraction in cold weather. They call this a method of polymerization, the dictionary definition of which is to treat the material so as to form molecules of higher atomic weight.

Experiments were conducted at Saranac Lake by the manufacturers, in 1929, under winter conditions, the lowest temperatures reached being − 20° F. At Burlington, New Jersey, somewhat similar experiments were performed in 1931 with temperatures ranging from − 2° to 100° F. In July, 1933, experiments were conducted in Los Angeles with steel plates treated with this coating, hung vertically in an oven for 24 hours at 150° F. without evidence of creeping. The same plates were then turned into a horizontal position, with the coating on the underside, and left for 24 hours at 150° F. without evidence of sag. They were then placed immediately in a refrigerator with a temperature of 0° F., with no evidence of cracking or sagging. The last series of tests was undertaken in order to give justification for lining of 147 tons of 48-in. pipe to be laid above ground at Los Angeles, Cal.

It might be interesting to note that in the Parsippany work, on the

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25 miles laid, there were only five defective lengths returned to the foundry on account of unsatisfactory lining. The writer's office maintained a very thorough engineering inspection at the foundry during the casting and lining of the pipe for this work.

It should also be stated that in making taps on the Parsippany work a certain amount of chipping from the lining flaked off from the pipe and was afterwards removed from hydrants in flushing out the mains. The manufacturers advise me that the coating manufactured under the new process has more elasticity and greater bond than before so that trouble from this source is largely eliminated. We also discovered that in cutting pipe, there was a certain amount of scaling on the ends of the cut sections, but this was not a serious matter because when discovered, it could be easily remedied by hand brushing.

While in the opinion of the writer the use of bitumastic lining is now so well established in so far as cast-iron pipe lines for water supply are concerned, the question is still open whether the advantage to be gained by the use of a lining in cast-iron sewer mains, offsets the added cost of such application. In this connection the writer was asked by Lynn H. Enslow if he could run a series of tests for the purpose of determining its present coefficient, on a 36-in. cast-iron sewer main laid by the writer in 1903. Perhaps this is an opportune time to give the results of this investigation, for there might be those who believe that while there are conditions in a *water* line that would justify the adoption of special provisions for the maintenance of a high coefficient, the passage of *sewage* through a cast-iron pipe may not have the same deteriorating effect upon the walls of the pipe as would water.

Tests recently made on a stretch of 1 400 ft. of this pipe, originally dipped according to the old-fashioned Angus Smith coating, show that the Williams-Hazen coefficient in the different tests varies from 96 to 98. Depth of flow during tests varied from 44 to 56 per cent. of the diameter, the higher values of "C" were obtained at the lower depths.

The physical condition of the walls of the sewer varies in different portions of the pipe section. The portion of the pipe below minimum flow is found to be smooth, showing little or no corrosion. This is partially true of the portion of the pipe above the average daily maximum flow for a vertical height of 8 to 9 in., or to within 6 in. of the top of the pipe. Uniformly for the entire length of the pipe, the top of the pipe is strongly corroded, which, on portions of the sewer, extends down to about the maximum daily flow-line. The walls of the pipe between the minimum flow and the average daily maximum flow are coated with a slimy crust for a vertical depth of 12 to 13 in. The walls of the pipe under the slime are strongly corroded for about two-thirds of the perimeter between maximum and minimum flow-line. The penetration of any portion of the corrosion is to a depth of about ¼ in. into the wall of the pipe. There seems to be no tuberculation on any part of the pipe.

This investigation was made for the purpose of determining whether or not it was necessary, in sewer lines, to go to the added expense of the application of the special coating. I think that the results of the observations clearly bring out the advantages of a coating, even on sewer construction. However, it should be pointed out that while the generally accepted coefficient of "C" in a cast-iron pipe in operation under average conditions for 30 years in water, is 85, a coefficient of 97 was found to exist in the cast-iron pipe sewer line under consideration.

It is interesting to note that that part of the sewer which was entirely submerged, was almost as smooth as when the pipe was constructed. That part of the walls within the limits of fluctuation of flow of sewage was corroded most. The coefficient "C" is undoubtedly most affected by the slime built up upon the walls of the pipe, this slime having a depth of ¾ in. The top of the pipe which is subjected to sewer gas was entirely pitted.

A conclusion can be drawn from the experiment that if a sewer was constantly full, there would be small, if any, deterioration with the use of ordinary tar dip; but few if any sewers are constructed under such conditions. There is always a variation between maximum and minimum flow, and very rarely in sewers except in siphons and force mains, do conditions exist where there is not a flow of gases, strong or dilute, along the surface of the sewage. For the preservation of the pipe it would seem that a permanent lining would be justified. A coefficient 20 per cent. less than the coefficient for new pipe was used in the original design of the sewer, so that after 30 years of service, there is little variation from the assumptions used at that time.

The work of entering the cast-iron sewer described, and of obtaining photographs of the interior, and making an examination as well as performing the tests for the determination of "C," was done by Mr. Herman Ohlgart, an Assistant Engineer in my office.

The experience gained with the use of Bitumastic Lining at Parsippany, justified the utilization of 5 000 ft. of 16-in. force main on a later project, which otherwise would have been scrapped. A change in the plan, after the construction of the West Orange, New Jersey, sewer system had been started, called for the construction of the sewer through a tunnel instead of a force line over the mountain. The higher coefficient obtained by lining the 16-in. pipe with Bitumastic Lining gave the required capacity with the pipe already purchased. The same capacity, of course, would have been secured by steepening the grade resulting in a substantial lengthening of the tunnel, but the cost of the lengthening of the tunnel was many times greater than the cost of applying the Bitumastic Lining to the 16-in. line already on hand.

CHARLES W. SHERMAN.* I have just concluded a series of flow tests of a part of the distribution pipe system in a town near Boston, and although

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the computations are not completed, the results have surprised me. The coefficients of flow are so low as to indicate the probability that I have previously underestimated the effect of the turbulence caused by hydrant branches, connections to cross streets, valves, and service taps themselves. Every corporation cock of course is tapped far enough into the pipe to avoid its stopping up by tubercles forming over the end. The result is equivalent to a good big tubercle.

The runs were only finished a few days ago, and such computations of results as have been made are preliminary. We found in a 6-in. cast-iron pipe, forty-three years old, a coefficient of 31. In that particular case the pipe did not have many hydrants or cross branches or services and ran along the edge of the town, adjoining a park reservation, where there were few branches or services to cause turbulence in the flow.

These particular tests were run on sections of pipe from 2 000 to 7 000 ft. long, forming a part of the distribution system. The side streets were gated off. The discharge was obtained by opening one or more hydrants at the far end and the flow was measured by a Pitometer inserted in general about half way down, all the experiments being made between midnight and 5:00 o'clock in the morning, when the domestic consumption was negligible. It being a fully metered town, the amount of water that did not travel the whole length of the pipe was very small.

As I said, on this 6-in. cast-iron pipe, forty-three years old, with comparatively few branches or services, we found a coefficient of 31. In an 8-in. pipe, with the usual number of cross-street connections, with hydrants 300 to 500 ft. apart, and with a considerable number of service connections, we obtained coefficients ranging between 40 and 44. In 10-in. pipe, forty-five years old, we found about the same coefficient, somewhere between 40 to 45. There was no 12-in. pipe which we could test that was as old. I think the oldest was about 20 years, and on that we got a coefficient in the neighborhood of 60.

Of course with small pipes the reduction in size has a marked effect on the coefficient; that is to say, the same thickness of incrustation has much more effect in reducing the coefficient in a small pipe than it has in a larger one.

CHARLES W. MOWRY.* May I ask Mr. Sherman why he thinks so much of the loss was due to the branch lines, hydrant connections and service connections, rather than to the natural tuberculation of the old pipe? Could not that same result have occurred in a straight line from natural tuberculation?

MR. SHERMAN. Because I find it difficult to believe that such low coefficient as my tests show can have resulted from tuberculation alone.

WILLIAM W. BRUSH.† In Brooklyn, New York, we frequently have 6-in. pipe show a coefficient of 20 or under, so that, Mr. Sherman's value of

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†Chief Engineer, Department of Water Supply, New York, N. Y.

31 is not nearly so low as we obtained with pipes which were about sixty years old at the time they were tested. That condition, in our judgment, has been caused virtually entirely by tuberculation, because many miles of that pipe have been taken out and examined as it was removed, and the appearance of the interior of the pipe was such as to lead us to believe in New York that the interference due to taps or due to hydrant branches or valves has been a very minor factor in establishing the low coefficient.

We usually test the pipes before a street is repaved to determine whether the coefficient is such as to justify the removal of the pipe before the new pavement is laid. For that reason we have a great many of these tests.

I think Mr. Killam's suggestion that our Association should have a committee, or in some manner should obtain the statistics that may be available as to coefficients, is a very desirable one. In our work at New York we have not attempted to present the records because the tests have been made by hydrant flow measurements, using a Pitot tube, and we do not pretend that they will have a high degree of accuracy. However, the degree of accuracy is such as to make certain that the results, when they are checked by many tests, will be reasonably close. I believe that we would be interested in seeing what is happening and has happened in pipes which are exposed to the soft and actively corrosive waters along the seacoast.

I think one difficulty we all realize is that we are now using pipes which are protected in a very different manner from formerly, so that what information we get as to different distribution systems and the condition of the pipes is perhaps more favorable from the point of view of determining what we should do in the way of reënforcing these distribution systems than it is from the point of view of what we should provide for in the future. If somebody will tell us what will be the condition sixty or seventy years from now of some of the pipes that have the protective coatings which are now used, we will be in a better position to design our distribution systems economically and intelligently. We would be very glad to furnish to a committee the full list of the tests we are making every year. There would be a large amount of data available, at least as far as the water of New York is concerned. The tests record the effects of water which is not nearly so active in corrosion as is the Catskill water. When the coefficient of discharge falls below 20, however, there is not much to be done. I doubt, therefore, that pipe which had been carrying Catskill water instead of Long Island water for sixty years would show an appreciably different coefficient.

MR. SHERMAN. One thing Mr. Brush said brought to my mind another suggestion. With so many of our public supplies chlorinated if much of the tuberculation comes from bacterial growth rather than from what we have been inclined to consider chemical corrosion, I wonder whether we

are going to have the same degree of loss of carrying capacity in pipes in the future, that we have had in the past.

HARRY U. FULLER.* At Portland, Me., a few years ago, we had a chance to get an idea of the relative value of the old and the new tar dip. It happened that we had to cut out, in cleaning a main, two sections of the pipe. We knew that one of those sections was thirty-five years old, the other about twelve years old. The twelve-year old pipe was in worse shape, so far as the condition of the coating was concerned, than the thirty-five-year old pipe. I have heard of other similar cases.

THOMAS H. WIGGIN.† I was very much interested in Mr. Sherman's supposition that an important part of the friction loss in distribution systems is due to fittings and taps. I am inclined to believe that the condition of the pipe interior determines the loss of head rather than the fittings; the effect of the latter can be estimated with some degree of accuracy from experiments which have been tried in the past. It seems to me that the only missing factor is the effect of taps, and that it would be interesting to make some experiments to show what influence the taps do have.

The reason I think that the surface of the pipe is important, and is the main cause of decreased capacity, is that I have run a number of tests from time to time and have been greatly surprised at the results. A small amount of roughening of the surface or of deposit on the interior surface of a pipe will cause a tremendous loss in carrying capacity. Some years ago I tested a long 16-in. main which did not have many taps or fittings. That main had a flow coefficient varying in various parts from 65 to 80. The coefficient of 65 was reasonably understandable because not only had the pipe a rough surface from tuberculation but the tubercles had grown together causing a reduction in diameter of ½ to ¾ in. But the condition of the part of the line which tested at 80 was surprising. There was a different kind of corrosion in that part. It was cut open in a number of places as required by the cleaning process and showed only about 1/16-in. of corrosion or of deposit, and was not very rough. The cleaning by go-devil restored the coefficient to 110 or 115. The present owners have it cleaned every two years, or so, to keep the coefficient up and the cost of pumping down.

I have been surprised at the small use that has been made of improved coatings. I have had occasion to inquire into this a number of times. The cast-iron pipe people tell me that 10 per cent. or so would probably cover the present use of improved linings for pipes as compared with total sales. I have experimented with tar coatings off and on for nearly forty years and am convinced that a tar coating cannot be produced by ordinary means to give a sustained coefficient except in the extremely rare waters which do not attack pipe. I was convinced long ago that the tar had to be refined to remove the lighter constituents, and the coating had to be

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†Consulting Engineer, New York, N. Y.

of much more substantial thickness than ever applied in tar dipping. That is exactly what bitumastic enamel accomplishes, and we have now proved by sixteen or eighteen years of use that it is quite permanent. Cement lining of course has been proved longer than that, except that the kind of cement used now is different from the natural cement with which the original proof was made. There are available several kinds of good linings. To get any assurance as to sustained carrying capacity and pumping economy one of these should be used, but they are apparently not being employed yet to a great extent. This is the fact that I would like to emphasize.

I was much interested in Mr. Killam's proposal to get reliable coefficients. Several committees of which I have been a member have tried to arrange something of that kind. It was found that a good many experiments are of doubtful accuracy, and it was concluded that the way to secure accuracy would be to have a number of sets of proper instruments and a number of supervisory members of the committee, so that whenever tests were to be made, they would be made with instruments which were reliable and under some supervision; otherwise there would be doubts as to the accuracy of the instruments, the accuracy of the levelling between gage points and the general conduct of the tests. I think that if committees of the water-works associations and other engineering societies could be organized so as to take advantage of the good opportunities that exist for gaging pipes, there would be an accumulation of data which would be of very great use. I am convinced, however, that there have been a sufficient number of flow tests to prove without a shadow of doubt that it is poor economy not to use one of the improved linings in pipes.

GEORGE E. BOYD.* In confirmation of what Mr. Wiggin has said, it might be of interest to know something of the experience of gas companies. We have coated the outside of a great many thousand miles of gas pipe, but recently the gas companies have come to us and pointed out that even with such smooth interiors, as are common in a steel pipe, the friction loss in pumping gas is considerable. They consider for estimating purposes that the cost of a transmission line is $1 000 per inch diameter per mile and they say that ordinarily a 14-in. pipe would cost $14 000 a mile and a 12-in.—$12 000 a mile, but if they could obtain a lining smooth enough, they could secure the same capacity with 2 in. less diameter and save $2 000 a mile by using a 12-in. pipe. We are not in a position to help them very much because of the possible solubility of the lining in light oils which might be present now or later in natural gas, but I was interested to confirm Mr. Wiggin's point that slight roughness does cause considerable lessening in the capacity of pipe lines out of all proportion to appearance and with gases as well as liquids.

LAURENCE C. HOUGH.† I have never given much weight to the

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†Pitometer Company, New York, N. Y.

obstruction caused by taps and hydrant branches. I have never considered that they make as much difference as Mr. Sherman seems to think. Ordinarily there is a tap perhaps every 50 or 75 ft., and a hydrant branch every 500 ft. While in a long line the resistance due to these may add up to an appreciable amount, it does not seem to me that it is going to make as much difference as the resistance due to the actual condition of the interior of the pipe foot by foot, which will build up a whole lot faster than the resistance due to the occasional obstruction.

Low coefficients are not always caused by the condition of the coating. There are other factors, principally obstructions in the pipe, which will frequently give very low coefficients. Besides the ever-present possibility of a partially closed valve, there may be a joint which has been improperly run, allowing a large mass of lead to get into the pipe. There may also be bricks and other obstructions in the pipe. Any measurement of friction is open to considerable doubt, I think. There are a number of factors which are vague, and the exact condition of the interior of the pipe is always open to question on account of the possible presence of obstructions. We sometimes find pipes of the same age with greatly different coefficients. Sometimes the coefficient is high, sometimes low. I think that the quality of the water that is being handled is a large factor. Pipes of the same age with different qualities of water will give radically different results.

EXPERIENCES WITH WATER MAIN CLEANING.

DISCUSSION OF PAPER BY ARTHUR T. CLARK.

This JOURNAL, Vol. 47, No. 2, June, 1933, p. 184.

WILLIAM R. CONARD.*

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As is indicated in Mr. Clark's paper, there is in each piece of cleaning work an individuality. While new information does not always result, some confirming information will be derived, and in many cases something new will develop, to add to facts already available.

The following cases have come under the writer's observation.

Case 1. Two miles of 10-in. force main. The necessity for cleaning was layer of manganese over the entire interior surface presenting a rippled appearance and creating a pumping head of 102 to 104 lb. per sq. in. in order to get through the line from 765 000 to 855 000 g.p.d. After cleaning the volume rose to 1 100 000 to 1 200 000 g.p.d. at 90 to 92 lb. per sq. in. head, or a capacity increase of 40 per cent. and a friction-head reduction of 47 per cent.

Case 2. Twelve thousand ft. of 18-in. gravity line, which in addition to some tuberculation, had a clay-like slimy deposit. This line was some 18 years old and the flow had gradually been reduced to about 4½ m.g.d. After cleaning, flow increased to 7 m.g.d. or a betterment of 55½ per cent. In addition to the deposits removed by cleaning a railroad tie was dislodged and brought out.

Case 3. Two miles of 10-in. force main, with the interior covered with tubercles. The pumpage through this main was 1 850 000 g.p.d. against a head of 93 lb. per sq. in. before cleaning. After cleaning the capacity was 2 140 000 g.p.d. with a pumping head of 85½ lb. per sq. in. This cleaning gave an increased capacity of more than 15 per cent. and a reduction in pumping head of 7½ lb. per sq. in.

Case 4. Four miles of 10-in. force main, and 4½ miles of 12-,10-, and 8-in. distribution mains.

The distribution pipes were highly tuberculated; the deposits being mostly hard and clinging tightly to the pipe. The force main was not so badly tuberculated, but had a deposit of red rust ⅛ in. to ¼ in. thick which clung tenaciously to the pipe interior and which flushing would not dislodge.

Taking these lines as a whole, the conditions were approximately as follows: — With the standpipe at the far end of the system away from the pumping station a total pumping head of 137 lb. per sq. in. yielded 600 000 g.p.d. before cleaning. After cleaning the yield was over 820 000 g.p.d.

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at 97-pound pumping head, an increase in capacity of about 45 per cent. and a reduction in head of nearly 30 per cent.

The economics of these four cases naturally vary with the results of cleaning and with other operating conditions. These it would require study to determine, but they are cited as typical of numbers of others and are given to indicate some of the benefits accruing from the cleaning of water mains both of the force and gravity type.

As indicated in Mr. Clark's paper, where a program of cleaning is carried out it is good economy to maintain a record of the location and manner of work against possibility of subsequent cleaning, and also to provide future cleaning by suitable connections in the pipe lines themselves.

From a financial point of view, it is seldom that cleaning fails to return a good dividend on the money spent and for that reason alone pipe cleaning is worth consideration.

WATERBORNE DISEASE IN NEW YORK STATE.

BY EARL DEVENDORF.*

[*Read September 21, 1933.*]

Much has been written on the marked reduction of typhoid fever and other intestinal diseases. The relation of improvements in water supplies to reduction in deaths from typhoid fever and other intestinal diseases in New York State was discussed by Charles A. Holmquist, Director of the Division of Sanitation of the New York State Department of Health, in this JOURNAL, Vol. 38, 1924, p. 237. Since that time typhoid fever has continued to decrease. An examination of Table 1 showing typhoid-fever case and death records for New York State indicates clearly, however, that the reduction would have been still greater had it not been for sporadic waterborne outbreaks, some of great magnitude, that have occurred as a

TABLE 1.— TYPHOID FEVER IN NEW YORK STATE (exclusive of New York City, State Institutions, and non-resident cases and deaths) BY FIVE YEAR PERIODS, 1913–1932.

	1913–1917.	1918–1922.	1923–1927.	1928–1932.	Total.
Mean Population	4 613 146	4 799 788	5 233 765	5 622 859	...
Typhoid cases	3 087	1 809	1 339	641	6 876
Typhoid deaths	461	250	160	76	947
Mean morbidity rate per 100 000	66.9	37.7	25.6	11.4	...
Mean mortality rate per 100 000	10.0	5.2	3.1	1.4	...
Waterborne outbreaks of typhoid fever:					
(*a*) Number	24	22	16	4	66
(*b*) Number of cases	731	915	758	342	2 746
(*c*) Number of deaths	55	81	62	24	222
(*d*) Case fatality, per cent	7.52	8.85	8.18	7.02	8.07

Note: These records were prepared by and obtained from Dr. George Ramsey, Director, Division of Communicable Diseases, New York State Department of Health.

result of breakdowns in the efficiency of water-purification processes and through the introduction of pollution to the water supplies through cross-connections with auxiliary polluted industrial or fire supplies. In fact, the prevention of breakdowns in the efficiency of water-purification plants and the safeguarding of water supplies against pollution through cross-connections have engaged the attention and best efforts of municipal and public health officials throughout the length and breadth of New York State.

In Table 2 is given a list of waterborne typhoid-fever outbreaks which have occurred in New York State from 1920 to 1932, inclusive. These out-

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breaks were outstanding either in their magnitude or in the manner by which infection of the water supply occurred. I shall endeavor to review briefly the more important of these waterborne outbreaks of typhoid fever that have occurred in New York State since 1920.

Regulation 2 of Chapter II of the New York State Sanitary Code requires practicing physicians to report all cases of typhoid fever to the local health officer who in turn is required to report the same to the Division of Communicable Diseases of the State Department of Health. Where there is any suspicion that the cause of infection may be due to a public

TABLE 2.— OUTSTANDING WATERBORNE OUTBREAKS OF TYPHOID FEVER IN NEW YORK STATE, 1920–1932.

Year.	Municipality.	Cases.	Deaths.	Cause.
1920	Schenectady.....	65	2	Flood.
1920	Amsterdam.....	22	1	Cross-connection.
1920	Seneca Falls.....	103	6	Cross-connection.
1920	Mt. Vernon.....	14	0	
1921	Gouverneur.....	85	4	Interruption in chlorination.
1924	Albany.....	114	14	Flood.
1926	Akron	284	21	Flood and interruption in chlorination.
1926	Addison.....	57	1	Pollution entering surface supply.
1926	Rochester.....	24	4	Cross-connection.
1927	Oswego.....	10	2	Cross-connection.
1927	Cohoes.....	48	5	Cross-connection.
1927	Albany.....	30	3	Cross-connection.
1928	Olean.....	238	21	Flood and interruption in chlorination.
1930	Royalton, town...	83	2	Pollution of private well water.
1933	Niagara River....	0	0	Unusual and unprecedented pollution affecting water supplies of many municipalities.

water-supply infection, the Division of Sanitation of the State Department of Health is called upon to investigate the water supply. The descriptions of the outbreaks given below are taken from records of the Division. No attempt has been made to list every waterborne oubreak which has occurred since 1920. The outbreaks listed are those which were well defined and which illustrate different manners of infection of the water supply.

Schenectady. In April, 1920, an epidemic of typhoid fever occurred following cases of gastro-enteric disturbance among the residents of the city. Preceding the appearance of the enteric disturbance there was a noticeable turbidity in the water supply, which is derived from three large wells on the south side of the Mohawk river and pumped from these wells to the city by electrically driven pumps. Although information was not received until several days after the beginning of the outbreak, an engineer was at once sent to investigate the condition of the water supply to determine whether or not the condition of the supply had been such as would be likely to cause the disturbances reported.

Originally, steam pumps were used to pump the water to the city, and the steam pumps in addition to being connected to the wells had two 24-in. cast-iron suction pipes extending to an intake in the Mohawk river some 700 or 800 ft. for use in case of emergency. Both of these suction pipes which passed through Well No. 1 above the normal water line were laid on each side of the well in brick tunnels with gravel bottom. Later the steam plant was abandoned. At that time the suction pipes were disconnected and the sections passing through the wells removed and the

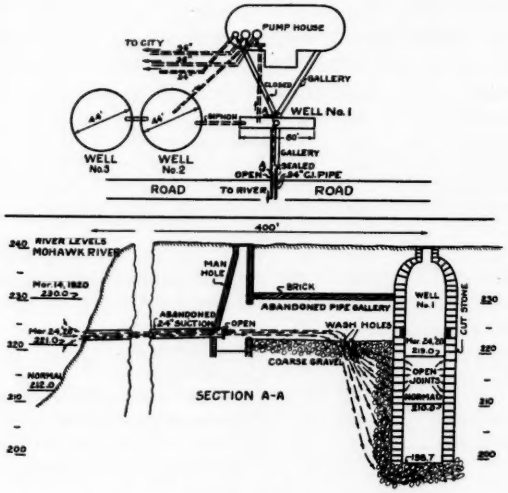

FIG. 1. — TYPHOID FEVER EPIDEMIC AT SCHENECTADY, N. Y., 1920.
Sketch shows course of polluted Mohawk River Water through Abandoned Suction Pipe and Pipe Gallery into Well.

masonry wall of the well sealed. Later in 1919, the city authorities in remodeling the pumping station had removed portions of the suction pipes in the tunnel adjacent to the well. At the north end of the tunnel, however, the pipes were left in place, the ends projecting into the tunnel. One of these ends had been carefully sealed with concrete, but through some oversight the other had been left open. Under normal conditions this caused no trouble, because the end of the open pipe was above high water in the river. See Figure 1.

On March 13, 1920, due to thaws and ice jams, the water in the river rose to an unusual height, about 7 ft. above the bottom of the open abandoned suction pipe to the river, and then slowly fell until it was below the bottom of the pipe again on March 20. Thus, for seven days, there was nothing to prevent the polluted water of the river from flowing through

the pipe into the tunnel and thence down through the few feet of coarse gravel into the well. The fresh deposits of river silt in the tunnel and the wash holes in the gravel bottom of the tunnel found at the time of the inspection indicated plainly what had occurred. An extraordinary high turbidity of the water which is normally clear was noticed in the city on the 13th and 14th of the month. This turbidity diminished rapidly and disappeared in a few days.

On March 15, the second day after the extreme high water, and during the few following days a large number of cases of gastro-enteric disturbances were reported. A little later during the last part of March and the first part of April, fifty-three cases of typhoid were reported, three of which terminated fatally. The larger part of the onsets occurred between April 1 and 6, or from eighteen days to three weeks after the extreme high water in the river.

When the cause of the turbidity in the water and the unsatisfactory bacteriological quality were brought to the attention of the city authorities by the Engineering Division of the Department of Sanitation, they immediately sealed the open end of the pipe and later removed a portion of both of the old suction lines between the well and the river, thus precluding any possibility of future pollution of the water supply from the same cause.

This outbreak is interesting because of the clearly defined manner in which the effects followed the cause and also because it illustrates how easily the trouble could have been avoided by the careful supervision of the water works in the first place and how the effects might have been mitigated had the first warnings indicated by the sudden appearance of turbidity in the water supply been heeded.

Amsterdam. In the fall of 1920, an outbreak of typhoid fever due to a cross-connection occurred in the city of Amsterdam, N. Y., among the employees of a mill.

Although officials of the mill denied that there were any cross-connections between the drinking-water supply obtained from the public water-supply of the city and the auxiliary polluted industrial supply obtained from a creek, the investigation revealed that all the cases were confined to the employees of a certain section of the mill having access to a single drinking-water line. Upon detailed inspection of the mill piping-system with the chief engineer of the mill, this drinking-water line was found to have been cross-connected through a single globe and check valve with the industrial supply. The mill authorities were not aware that this connection had been installed by the plumber in order to make available the higher pressure of the city supply for use in operating a hydraulic press. Upon discovery, the cross-connection was immediately ordered disconnected, and the outbreak subsided. The first samples collected from the drinking-water line on the initial day of the inspection showed the drinking-water supply to be polluted. The chemical analysis of a sample collected from the drinking-water line also showed the water to be chemically

different from the city supply, both in regard to hardness and chloride content. The cross-connection, however, had been discovered and eliminated before these analyses became available. There were 22 cases of typhoid fever among the employees of this mill with one death.

An interesting feature in connection with this outbreak is that the death which occurred was the first instance in New York State in which the State Industrial Commission held typhoid fever to be compensable under the State Industrial Act.

Gouverneur. The reports on investigations following the occurrence of a number of cases of typhoid fever in 1920 among residents of the village of Gouverneur indicated the chlorination apparatus to be clogged and operating unsatisfactorily. The apparatus at the time of the investigation was immediately overhauled and again placed in proper operating condition. The water supply of the village is obtained by pumping from the Oswegatchie River, which is seriously polluted.

It is significant to note that this supply had been considered by the Department to be too grossly contaminated to be rendered safe by chlorination alone, especially in view of the fact that the application of chlorine may be interrupted, during which periods raw or improperly chlorinated water would be pumped into the mains. The State Commissioner of Health has recently ordered this village to proceed with the installation of a filtration plant, and this matter is now pending.

Mt. Vernon. Fourteen cases of typhoid fever were reported from Mt. Vernon and vicinity during the months of March and April, 1920. Upon investigation, these proved to have been caused by the irregular application of alum and chlorine to the water for a short period. The water supply is obtained in part from the Mamaroneck River and in part from the Hutchinson River and Tom Paine Brook. Both supplies are filtered and chlorinated before being delivered to the mains. Upon investigation, it was learned that on account of illness the engineer in charge of the station was not able to attend to the application of chemicals and had left the work to his assistant, who was not entirely familiar with the details of controlling their application. At the same time, difficulty was experienced with the chlorination apparatus, and it was found crated at the time of the inspection and ready to be shipped back to the manufacturer for repairs. During this period heavy rains and thaws occurred on the watershed, causing an extraordinary amount of polluted material to reach the stream and therefore making the careful application of the chemicals more necessary than under normal conditions.

The extraordinary pollution of the river due to the rains and thaws occurring at this time and the irregularity of application of chemicals made it certain that the quality of the water was below normal and that it probably contained active contamination. The onsets of the typhoid fever cases occurred some 17 to 20 days after this period of probable maximum pollution of the water supply.

Albany. Early in April, 1924 the Division of Laboratories and Research of the State Department of Health reported to the Division of Sanitation the presence in the Albany supply of *B. coli* in dilutions as small as 1/10 cc. This matter was immediately taken up with the city authorities.

For a better understanding, it may be well to describe briefly the conditions existing at the time. The water supply of the city of Albany was obtained from the Hudson River at a point about a mile north of the Quackenbush Pumping Station. The water, after filtration and chlorination at the filter plant, flowed by gravity through a steel conduit laid in the bed of the old abandoned Erie Canal. Just prior to the outbreak following heavy rains, the level of the river rose, flooding the canal. On recommendation of the State Department of Health, provisions were immediately made for chlorination of the water at the Quackenbush Pumping Station. The city authorities at the time of the investigation were advised that the Department locked with suspicion upon the conduit and felt that until the conduit was abandoned or replaced all water should be chlorinated continuously at the Quackenbush Pumping Station. A total of 114 cases of typhoid fever, with 14 deaths, occurred in the city of Albany. The cause of this outbreak following an investigation was held to be due to pollution entering the supply in the gravity conduit. The results of analyses made by George E. Willcomb, Chemist in charge of the Albany water plant indicated the water delivered from the filtration plant had been above suspicion for many years.

Subsequently, in 1927, another outbreak of typhoid fever occurred in the city of Albany, largely localized in North Albany. Upon investigation, three cross-connections were found between the public water-supply and an auxiliary polluted supply at an industrial plant in that section of the city. It is interesting to note that the city authorities subsequently passed regulations requiring that all plants, where auxiliary sources of supply were available, install a system of double check valves on the city-water line entering the plants. Such double check valves were required whether the supply was potable or not and whether or not there were present cross-connections between the two supplies, the purpose being to prevent possible pollution of the public water supply through an unauthorized cross-connection being installed between the two supplies without the knowledge of the city. In this latter outbreak there was a total of 30 typhoid cases with three deaths.

Akron. In the early part of October, 1926, one of the most serious typhoid fever outbreaks which has occurred in any section of the state in recent years was caused through insufficient chlorination of the water supply. The public water-supply of the village of Akron at that time was obtained by pumping from a well in a limestone formation, the well being adjacent to the creek below the general level of the village. Following heavy rains just preceding the outbreak, the level of the creek and of the

well itself rose several feet in height. Upon receiving a report from the District State Health Officer of the occurrence of a large number of cases of dysentery, the author left late on Saturday night and made an inspection on the following Sunday morning, accompanied by the District Health Officer. At the time of the inspection, it was found that an insufficient amount of chlorine was being applied to the water, as indicated by the starch iodide test. No records were being maintained of the amount of chlorine applied, and no tests were being made for residual chlorine to serve as a guide to the operator in the application of chlorine.

In the past, the village of Akron had had occasional cases of typhoid. In 1920, following an inspection by an engineer of the Department, the village authorities were advised to seek a new and safer water supply and, until such supply could be secured, to chlorinate the water, making frequent tests to insure use of sufficient chlorine. At that time, the local chamber of commerce attempted to initiate a movement for a new water supply. Chlorination apparatus was installed, but the village continued to use the polluted water supply.

The village was practically prostrated by this catastrophe which came upon them unexpectedly, although not without warning from the Department. Dr. Matthias Nicoll, Jr., State Commissioner of Health at the time, assigned two additional district state health officers and ten department nurses to assist in caring for the sick. Ten nurses were also sent by the Erie County Chapter of the Red Cross; in addition about 50 private nurses were on duty. Among the 2 000 residents of the village a total of 284 cases of typhoid occurred, with 21 deaths. This outbreak offers a striking illustration of the danger of depending upon chlorination alone for the treatment of a water supply subject to serious pollution. The village has since abandoned the polluted well supply and has developed an adequate and safe upland supply which is filtered and chlorinated.

Rochester. An outbreak of typhoid fever occurred among employees of a department store in Rochester in 1926. It developed that there were two storage tanks located on the roof of the building, one furnished with the public water supply and the other with water pumped from a sump located underneath the building. The piping systems of these supplies were cross-connected and provided with gate valves in addition to a check valve. On account of some changes being made in the plumbing in the store the drinking-water supply was shut off for a time. There were 24 cases of typhoid fever with four deaths resulting from the outbreak. The cross-connections were severed as soon as discovered, and the outbreak subsided.

Oswego. In 1927 an outbreak occurred among the employees of an industrial plant in the city of Oswego. Upon investigation by an engineer of the State Department of Health it was found that there were three possible sources of contamination: (1) through mains carrying city water in the mill which were cross-connected with an auxiliary fire and industrial

supply obtained by pumping from polluted harbor water; the cross-connection being provided with double check and gate valves of the special Factory Mutual type with rubber gaskets; (2) a drinking-water supply used in the mill during the summer months and obtained by pumping from a well driven through 500 ft. of sandstone; (3) a cross-connection between one of the drinking-water supply lines in the mill and the industrial supply line.

The investigation revealed that the city water department made regular tests and examinations of the double check valve installations which were found to be satisfactorily maintained. The well from which the auxiliary drinking-water supply for the mill was obtained was found to be satisfactorily located, and analysis indicated that the water was of safe, sanitary quality. The cross-connection between the drinking-water supply-line and the industrial supply, however, which was installed to operate a steam pressure-regulator was immediately removed. Upon removal of this cross-connection, the outbreak subsided. There were in all 10 cases, two of which terminated fatally.

Cohoes. In 1927, a number of cases of typhoid fever occurred among the residents of the city of Cohoes. The investigation indicated that the cases were concentrated in a limited area in the southern end of the city in the vicinity of four industrial establishments. At one of these plants, a connection between the city supply and an industrial supply normally using canal water was found to exist. The industrial supply flowed from the canal by gravity to a suction tank in the basement of the building from which it was pumped throughout the piping system of the mill by a motor-driven centrifugal pump at a pressure of about 35 lb. per sq. in. A 6-in. connection from the city main lead to the building, from which a small line was taken off for supplying the wash rooms and drinking fountains. This 6-in. line was cross-connected with the industrial supply of the mill and was provided with two standard gate valves but no check valves.

It was learned that the city supply, which was used rather infrequently by the mill when the canal water became turbid, had been used for some four or five weeks prior to the time of the inspection, although the exact date could not be ascertained. It was learned, moreover, that there had been an occasion just prior to the outbreak when the pressure in the mains in this section of the city had been reduced due to the water supply being shut off for repairs and replacement to the system. It became apparent, therefore, that with the lowering of the water in the city mains during periods of making repairs and with the opening of the valve on the cross-connection at the industrial plant to allow the use of city water, both of which occurred during the period of incubation of the reported cases of typhoid, there existed conditions favorable to the entrance of polluted water into the city mains through the cross-connection. Samples of water collected from the city hydrants in this section of the city at the time of the outbreak indicated the presence of pollution in the vicinity of the

industrial plant, whereas the samples collected from hydrants in other sections of the city were free from pollution. Upon discovery, the cross-connection was immediately eliminated. As a result of this outbreak there were in all 48 cases of typhoid fever, 5 of which terminated fatally.

Olean. During September and October, 1928, there occurred in the city of Olean 238 cases of typhoid fever and 21 deaths. The public water-supply of the city was derived from two sources, namely, a filtered and chlorinated supply from Olean Creek and a chlorinated supply from South Olean wells pumped directly into the distribution system, the excess over consumption being discharged from the system into two open storage reservoirs located on the hill to the south of the city.

The South Olean well-supply came partly from a large dug well on the south side of the Allegheny River and partly from twelve or more 6- and 8-in. tubular wells sunk in the low ground on the north side of the river. Formerly these wells were all located some distance from the river, but in recent years at least two of them became submerged due to a change in the course of the stream. The Allegheny River at this point is grossly polluted by sewage from nearly half the city of Olean.

The tubular wells on the north side of the river were about 72 ft. deep and passed through successive layers of soil, clay and sand into water-bearing gravel. The upper ends of these wells were connected in two groups by 10-in. screw-joint piping, the two connecting lines leading across the river on the river bed into the dug well, where a suction pipe operating through a vacuum pump drew the water out of the tubular wells into the dug well. From this well, containing a mixed ground water from both north and south of the river, the water was discharged by an electrically operated pump into the system and the two reservoirs.

For many years, this well water supply had been regarded by the State Department of Health as likely to become polluted, partly because the surface of the ground into which the wells were driven had occasionally been flooded when the river was high and partly because of the certainty of pollution should a break occur in the piping system submerged in the river. The Department had repeatedly recommended to the water commissioners the necessity for continuous and effective chlorination of the South Olean water supply, the efficiency of treatment to be checked daily by tests for excess chlorine.

The records of operation of this supply for the months of July and August, 1928 indicated that tests for excess chlorine were made daily and that enough chlorine was added to give an excess of from 0.1 to 0.2 p.p.m. as recommended. However, it was found that these tests were not made daily but only at infrequent intervals. By failure to make these tests, evidence of pollution was not detected. The amount of chlorine actually used would probably have been sufficient, had not heavily polluted river water entered the system, but it was entirely insufficient when that occurred. On the other hand, had enough chlorine been added to give the excess

indicated on the records, the increased amount of chlorine required to produce such an excess would have immediately indicated pollution.

An examination of the automatic Venturi meter records giving the amount of water pumped showed extreme fluctuations in the pumpage during the months of July, August and September. The pump on these days apparently lost its suction intermittently and failed to deliver water. This was confirmed by the log of the Niagara, Lockport and Eastern Power Company which supplies the power for operating the pump.

On September 8, a man fishing in the river heard, it is said, a sucking sound, like the arcing of a high-tension power line, in the vicinity of one of the submerged wells. This fact was reported to the water superintendent on September 10, and he found the suction pipe of one of the wells broken and immediately cut out this well.

Direct contamination of the city water-supply came through a break in the connecting pipe from the submerged well so that the water supply of the city became grossly polluted, and coupled with the fact that additional chlorine was not added to care for this pollution, caused the epidemic of typhoid fever.

Gasport. In September, 1930, a typhoid-fever outbreak occurred at Gasport, N. Y., following a church festival. In all there were 83 cases of typhoid fever with two deaths. Investigations made by the Division of Communicable Diseases excluded infection by milk, ice cream or other food. The water supply used during the festival was obtained from wells on the two adjacent properties, from the church well and from a cistern at the church. Both of the well supplies on the adjacent properties were tested and found free from *B. coli*, as was also the cistern water. The church well, however, showed the presence of organisms of the *B. coli* group in all volumes examined as small as 1/10 cc.

The location and construction of the church well, moreover, was very unsatisfactory from a sanitary standpoint. It was found in the basement of the church not more than ten feet from the church cesspool. The well was a shallow drilled structure 6-in. in diameter and approximately 26 ft. deep. The well was cased for about 4½ ft. below the basement floor, and for a short distance below this casing the well was drilled through stratified limestone before reaching relatively solid rock. The investigation revealed that a known typhoid carrier spent all day at the church a short time previous to the occurrence of the outbreak and admitted using the church toilet on several occasions. The combination of circumstances: — low ground-water level, excessive hydraulic lift due to the unusual use of the well at the time of the festival, overtaxing of the sanitary system, the known presence of a carrier using these sanitary facilities together with the explosiveness of the outbreak and the large number affected, and the negative findings as to probable infection from other causes, lead to the justified conclusion that this outbreak was due to the polluted water from the church well. See Figure 2.

Pollution of Niagara River. On March 14 and 15, 1933, a so-called "wave" of pollution passed down the Niagara River, resulting in the serious overtaxing of water-purification plants along the river and later affecting the operation of many plants on Lake Ontario.

In the early part of April, the American Channel of the Niagara River was subjected to one of the most severe ice jams on record. For days the channel was completely blocked with ice. Ice was piled in the river to a height of three to five feet and, considering the depth of the channel, must have rested on the bottom in many places. Difficulty was experienced

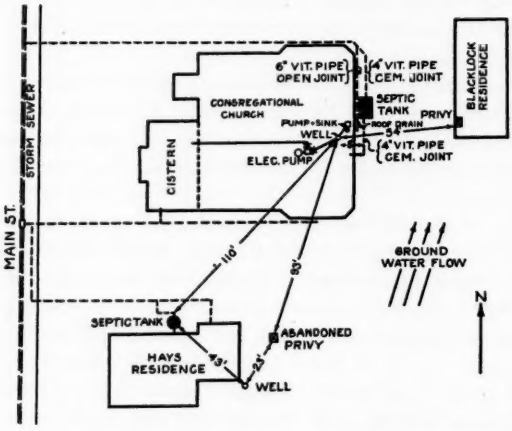

FIG 2. — TYPHOID FEVER EPIDEMIC AT GASPORT, N. Y., 1930. Pollution probably entered church well from sewage disposal system.

at some of the water-supply intakes in obtaining sufficient water to supply the municipality. At infrequent intervals, the entire ice field would move for a few hours and then stop. Under these conditions, the raw water at the Niagara River plants possessed normal chlorine demands except on three occasions, when waves of pollution followed by a few hours the general movements of ice in the river. The investigation by engineers of the Department of Sanitation indicated that return waves of pollution occurred and that they decreased chronologically in intensity and followed by several hours the beginning of a general ice movement in the American Channel. These findings, in view of the severe ice conditions in Buffalo Harbor and at the entrance of the Niagara River at the time indicated that polluted harbor water for limited periods of time was prevented by the ice blockade from reaching the Niagara River in a normal manner and that these impounded waters were discharged to form an abnormal proportion of the flow in the Niagara River at times when the general move-

ment of ice in the American Channel occurred. The evidence obtained indicated overwhelmingly that the source of pollution was general sewage and wastes from the city of Buffalo, principally from Buffalo River.

The "wave" of sewage pollution which started down the Niagara River on March 14, 1933, threatened every water-purification plant in New York State located along the Niagara River, Lake Ontario, and the St. Lawrence River and affected the operation of the water-purification plants at Tonawanda, North Tonawanda, Lockport, Niagara Falls, Lewiston, Youngstown, Wilson, Lyndonville, Charlotte (Rochester and Lake Ontario Water Company), Pultneyville (Williamson District Plant), Sodus Point, Oswego, and probably Massena.

The outbreak of diarrhea at Niagara Falls, following the difficulties experienced in the treatment of water on March 15, 1933, resulted from an unreasonable load placed upon the water-purification plant caused by sewage and industrial waste pollution from the city of Buffalo.

On March 15, 1933, the water supplies of Tonawanda and North Tonawanda and, on April 1, 1933, the water supplies of communities furnished by the plant of the Rochester and Lake Ontario Water Company at Charlotte were inadequately treated as the result of heavy burdens caused by Buffalo sewage and industrial waste pollution placed upon the respective purification plants, which in certain instances made it impossible to properly chlorinate the water with the equipment available. The residents of these several municipalities were for a period of several hours exposed to the dangers of drinking inadequately purified water.

Numerous investigations have been made by the New York Department of Sanitation of the pollution of the Niagara River, all of which have shown the Niagara River near the American shore to be seriously polluted as far down as Niagara Falls by the sewage of the city of Buffalo. Owing, however, to the great width of the river and the rapid velocity of flow, a marked horizontal stratification of pollution in the river occurs, the effect of which is to prevent sewage from intermingling with currents in the river for a distance from the American shore greater than about ¼ the width of the river and for a distance down the river at least as far as the Grand Island. Under the conditions that existed, however, during March and April of the present year, when the conditions of river flow were abnormal, horizontal stratification of the river water was not present with the result that pollution was carried beyond midstream and affected the water supplies of those cities located below Buffalo. The present menace to the water supplies of the municipalities on the Niagara River below Buffalo will continue until provision is made for the treatment of the sewage of the city of Buffalo. The city of Buffalo has this matter under consideration at present and has employed consulting engineers in the past who have made an investigation and prepared preliminary plans and estimates of cost for providing treatment of the sewage of the city. Consideration is also being given to the formation of a sanitary district to provide for treatment of the sewage of the municipalities located on the Niagara River.

It becomes apparent on studying the different classes of waterborne outbreaks that in a few of the cases it would undoubtedly have been difficult to predict the conditions which caused the outbreak, but in general this has not been the case, and in many instances the possibility of a waterborne outbreak has not only been apparent but has been pointed out by the New York Department of Sanitation in its reports on investigations of the public water supplies.

Discussion.

William F. Sullivan.* I would like to ask Mr. Devendorf if the cities and the industries responsible are held liable for outbreaks of typhoid fever, and if there is much litigation.

Mr. Devendorf. In the case of Olean the city has paid out in claims, up to the beginning of 1933, according to what the attorney told me, $425 000 that had been allocated through special acts of the Legislature. There were a few additional cases pending.

The case of the city of Albany was settled on the test case after an appeal by the city. The total amount paid, I do not know. I have always considered it embarrassing to ask a municipality how much it cost them to settle.

The case of Schenectady was settled out of court. What it cost I do not know. There was a suit in Cohoes.

Apparently the courts are increasingly holding the cities responsible. All cases hinge on whether the city can be shown negligent. If negligence can be proved the city is liable; if no negligence is shown the municipality is not liable. It was decided in the Mechanicville case that a city does not guarantee, and there is no implied warranty on the quality of the water, but negligence must be shown. That is the crux of the case.

Francis H. Kingsbury.† Is there a record of criminal liability on the part of a superintendent or operator?

Mr. Devendorf. That question came up in the Olean outbreak. In that case we had complete records of reports being submitted by the Department indicating tests made daily, the results of which we reported to the Board of Water Commissioners. The city of Olean, by a resolution, asked Dr. Nicoll, the State Commissioner of Health, to fix the responsibility. That was a difficult matter, but it was done. The report by the Commissioner to the city fixed the responsibility on the Board of Water Commissioners in the first instance. As in a great many municipalities, the Board of Water Commissioners did not realize the responsibility they were incurring. It was pathetic to find in that little community honest, well intentioned, well meaning individuals, who were held responsible for the outbreak.

With respect to the operator himself, the South Olean well was about

* President, Pennichuck Water Works, Nashua, N. H.
†Massachusetts State Department of Health, Boston, Mass.

two miles from the filter plant. All samples for the ortho-tolidine tests were taken to the filter plant where the sample was tested, and the result indicated on the report that was submitted to the Department. That proceeded along day after day, and the operator in his simple way fell into the habit of putting down a result whether he received a sample or not, apparently not realizing what he was doing. This information was obtained at the hearing. Every employee was man enough to declare himself and admit his fault. Nothing was done about prosecuting them criminally; but their responsibility was fixed, and we set the responsibility of the city as far as the settling of the suits was concerned.

MR. KINGSBURY. What I wanted you to bring out, and you have done so, is that in addition to the financial responsibility of the city there may be a criminal liability on the part of those charged with the operation and conduct of the water works.

MR. DEVENDORF. That is a gospel I have been preaching to all the water works men in our state. I have said, "No matter what happens, put it down on the record; if you put it down on the record you are not liable; if you do not put it down on the record and something happens afterwards, nobody knows what may be the result." I have used this Olean instance as an example, and I think we are now getting good results at Olean, honest results.

WARREN J. SCOTT.* I would like to say that I think a paper like Mr. Devendorf's is an excellent one to wake us all up. I think we are all in danger of being lulled into a sense of security in the absence of any waterborne outbreaks over a period of a few years.

We have had a recent outbreak in Connecticut in a mill where there were three connections with the public water-supply. One was a fire connection, which was protected by double check-valves that we inspected three times a year, one was a small connection to the drinking bubblers in the mill, and the third was a connection to supply water for flushing toilets and miscellaneous other uses in the mill. The mill, without the knowledge of the city authorities or the State Department of Health, a short time ago made a cross-connection with the city line so as to wash some pressure filters that served in filtering the river water which was used in process work in the mill. Instead of making the cross-connection in back of the check valves they made the cross-connection with one of the other lines. Twenty-five or thirty people in the mill came down with intestinal sickness, and the only thing that we could pin it on was the cross-connection. While we had no evidence of the lowering of the city pressure, which was normally higher than the mill pressure, the facts that nobody else in the city became ill and that there was a report of colored water in the mill at the time, with no evidence of any other highly colored water in the city, the city water being filtered, made it look very much as though the cross-connection was responsible.

* Chief Engineer, Connecticut State Department of Health, Hartford, Conn.

I think that water works superintendents would be doing a very good job if they made a check of the piping systems in all mills in their respective communities at least once a year. We assume, because we have safeguards on cross-connections, or because we have checked up at one particular time and found there were no cross-connections, that everything is all right now. We give plenty of care to our sources of supply, but we frequently do not give enough care to our distribution systems.

E. SHERMAN CHASE.* We are greatly indebted to Mr. Devendorf for presenting to us so graphically the possible dangers which still persist in connection with the sanitary qualities of many of our water supplies. In many instances the delays in carrying out the recommendations of state health departments very nearly constitute criminal negligence on the part of municipalities. There are probably a hundred water supplies in the state of New York, the local authorities of which have been repeatedly warned of potential sanitary hazards.

In the case of the Akron outbreak the intensity of the infection and the concentration of the disease in a small population is perhaps a record-breaking one, and I would like to ask Professor Winslow if he recalls any instance where the number of cases of typhoid was any greater in proportion to the population than in the case of Akron as cited by Mr. Devendorf.

C.-E. A. WINSLOW.† Since the figure in Akron was one in ten, Plymouth, Pa., appears to hold the record, because there were 1 100 cases in a population of 8 000 in the epidemic of 1885.

MR. DEVENDORF. Regarding the liability in the case of Akron, there were several taxpayers in the village on the point of bringing suit, but gradually it sank into the minds of everyone that if one brought suit all would bring suit and that they would be paying their own damages. They finally dropped the whole matter. I tried to spread that gospel among the people when I was there, and I don't know whether I was partially responsible for the action or not.

The case in the mill at Amsterdam was interesting. The mill, under the workmen's compensation act, was required to pay the widow of a man who died from typhoid fever, after having worked in this mill, $8 and some cents a week as long as she remained single. That was the first instance in our state that typhoid fever was held compensable.

MR. SULLIVAN. Was any action taken against the department store at Rochester?

Mr. DEVENDORF. To the best of my knowledge, there was not. I happened to be in Rochester at the time of the outbreak and advised the Health Commissioner and the Commissioner of Public Works. The cross-connection was found and eliminated. No publicity was given to the outbreak. The department store took every means possible to compensate the people affected by taking care of them, and as far as I know there was no suit.

* Of Metcalf and Eddy, Consulting Engineers, Boston, Mass.
† Yale University, New Haven, Conn.

PROCEEDINGS.

Fifty-Second Annual Convention.

Bridgeport, Connecticut.

September 19 to 22, 1933.

The following is a synopsis of such parts of the proceedings of the Fifty-second Convention as appear to be of value for the record.

The Fifty-second Annual Convention of the New England Water Works Association was held at the Stratfield Hotel, Bridgeport, Connecticut, September 19 to 22, 1933.

President Richard H. Ellis presided at the meetings.

Tuesday, September 19.

Morning Session.

The President. Gentlemen, it is a pleasure and privilege to open the Fifty-second Annual Convention of the New England Water Works Association.

Administrative Reports.

The Annual Reports of the Secretary, Treasurer and Editor were submitted by Frank J. Gifford, Albert L. Sawyer and Gordon M. Fair respectively. (See page 323.) These reports were accepted, on motion from the floor, duly seconded, and placed on file.

Progress Reports of Technical Committees.

Brief progress reports of technical committees of the Association were read by the Secretary as follows:

Committee on Standardization of Pipe Flanges and Fittings.—W. R. Conard and F. A. Barbour.

Committee on Simplification of Manhole Frames and Covers.— W. R. Conard and F. A. Marston.

Sectional Committee of American Engineering Standards Association for Specification of Cast Iron Pipe and Special Castings.— W. R. Conard, C. W. Mowry and A. L. Shaw.

These reports were accepted and placed on file.

A luncheon meeting of the Association, with the ladies present, was welcomed to Bridgeport by his Honor, Mayor Buckingham of Bridgeport and by Mr. Alfred V. Bodine, President of the Bridgeport Chamber of Commerce.

Closing of Polls.

The President. One hour having elapsed from the time of the opening of the meeting, during which there has been an opportunity to vote for officers of the associations for the coming year, I will declare the polls closed. The tellers will be appointed subsequent to this meeting.

(Messrs. Arthur C. King, William B. Duffy and Charles J. Crump were later appointed a committee to sort and count the ballots.)

Afternoon Session.

This session was devoted to papers descriptive of the Bridgeport Hydraulic Company's system.

A general description of the Bridgeport Hydraulic Company's system was given by Samuel P. Senior, President and Chief Engineer, Bridgeport Hydraulic Company.

A paper, "Method of Operation of Distribution System," was read by D. H. Hall, Superintendent, Bridgeport Hydraulic Company.

These two papers were discussed by Charles W. Mowry and Roger W. Esty.

A paper, "Purification Methods Employed by Bridgeport Hydraulic Company," was read by Frank C. Barrows, Chemist, Bridgeport Hydraulic Company. Harry U. Fuller, E. Sherman Chase and Samuel J. Kyle took part in the discussion.

A paper, "Water Shed and Forestation Work," was read by William C. Pollitt, Engineer, Bridgeport Hydraulic Company.

This paper was discussed by Truman M. Curry, Jr., H. W. Griswold, Theodore L. Bristol, H. J. Cook and L. H. Enslow.

Through the courtesy of Water Works Manufacturers Association a reception and dance were held in the evening.

Wednesday, September 20.

Morning Session.

Caleb Mills Saville, Manager and Chief Engineer, Water Bureau, Metropolitan District Commission, Hartford, Connecticut, gave an illustrated talk, "Some Phases of Southern New England Hydrology." Theodore L. Bristol and Charles W. Sherman took part in the discussion.

An illustrated paper, "Pipe Linings and Friction Coefficients," prepared by Elson T. Killam, Associate Engineer with Alexander Potter, New York, N. Y., was read by Mr. Potter who also presented a supplementary paper. Moving pictures showing the manufacture and handling of CEM-WRAP PIPE were shown by courtesy of the Wailes Dove-Hermiston Corporation. The discussion was participated in by Charles W. Sherman, Charles W. Mowry, William W. Brush, Harry U. Fuller,

Henry T. Gidley, Thomas H. Wiggin, George E. Boyd, John L. W. Birkinbine and Laurence C. Hough.

An illustrated paper, "A Ten Foot Parshall Measuring Flume at Providence, R. I.," was read by Charles G. Richardson of the Builders Iron Foundry, Providence, R. I. Alexander Potter and Francis B. Marsh took part in the discussion.

During the afternoon an inspection trip was made to the Bridgeport Hydraulic Company's sources of supply, stops being made at the Hemlocks, Easton and Trap Falls reservoirs.

Through the courtesy of the Water Works Manufacturers Association a dinner was served in the main dining room of the Stratfield Hotel to the members and guests.

Award of Dexter Brackett Memorial Medal.

President Ellis. The New England Water Works Association has but few honors that it can confer upon distinguished members. I would like at this time to announce the action of the Executive Committee in some of its recent votes.

In commemoration of one of the early and leading members of the Association, there has been established the custom of awarding the Dexter Brackett Memorial Medal to the member who has, within the previous calendar year, presented to the Association the paper deemed most meritorious. The committee on the award, after carefully reviewing the excellent papers presented, selected, for his treatment of the subject, "Water Consumption During Fires," Charles W. Mowry, Manager of the Inspection Department, Factory Mutual Fire Insurance Companies. It gives me great pleasure, Mr. Mowry, to award to you the Dexter Brackett Memorial Medal.

Charles W. Mowry. Mr. President, Officers of the Association, Members of the Association and Guests: Sometimes the things we least expect afford us the greatest satisfaction and pleasure. That is the position I am in tonight, because I can assure you that this honor was wholly unexpected.

One of the many advantages of membership in this Association is the opportunity which it affords of meeting and knowing men who are doing worthwhile and interesting things, and who are upholding high standards in their profession. It is a stimulating influence, and it gives a desire to contribute our little bit, however humble that may be.

I feel very greatly honored that my contribution was considered worthy of this award. (*Applause.*)

Award of Honorary Memberships.

President Ellis. It has also been the custom of the Association to select, from time to time, among the water-works fraternity those men

who are outstanding in their field of endeavor and to honor them by election to honorary membership.

I call upon E. Sherman Chase, Chairman of the Committee on Honorary Membership, to present to you as honorary members three men who have been elected to this estate.

E. SHERMAN CHASE. Mr. President, members of the NEW ENGLAND WATER WORKS ASSOCIATION, Ladies and Gentlemen: The Committee on the Election of Honorary Members consisted of Warren J. Scott, Howard M. King and myself. We had great difficulty in selecting from the membership of this Association only three outstanding men. We are limited as to the number of Honorary Members. There were so many eminent and deserving men that it was a hard task to confine ourselves to three. Had the number been thirty the work would have been easier.

William Whitlock Brush, Chief Engineer of Water Supply, Department of Water Supply, Gas and Electricity of New York City, a member since 1902, has been an active participant in the various activities of this Association, served as an officer, as a committee member, and has been a contributor of numerous papers. Mr. Brush has in his charge the delivery of more water to more people, with the exception of London, than any other man in the world. Modest, friendly, capable — it gives me great pleasure to introduce to you as an Honorary Member of this Association Mr. Brush. (*Applause.*)

Most of our members have achieved eminence in the water works field alone. The Hon. William F. Sullivan, Mayor of Nashua, New Hampshire, President of the Pennichuck Water Company, has achieved distinction in that broader field of human endeavor known as politics; politics of the best kind in the best sense of the word. Mayor Sullivan has been a member of this Association since 1900; he has been a president of the Association, an active worker, a participant in all of its activities. He has had long experience in water-works management, working his way up from the bottom to the presidency of a water company. It gives me great pleasure to introduce to you as a new Honorary Member, Hon. William F. Sullivan of Nashua, New Hampshire. (*Applause.*)

The third member whom we have selected for honorary membership is Robert Spurr Weston, Consulting Engineer of Boston, a member of this Association since 1897, a Past President, chairman of many committees, contributor of numerous papers, wholehearted, loyal member of the Association. Mr. Weston has long been interested as an expert in the quality of water supplies and in the manner of their purification. No meeting of this Association is complete without his genial presence. I take great pleasure in introducing to you Mr. Weston. (*Applause.*)

THURSDAY, SEPTEMBER 21.

Morning Session.

A paper, "Modern Developments in Chlorination Practice," was read by L. H. Enslow, Editor, *Water Works and Sewerage*, New York, N. Y. E. Sherman Chase, Frank E. Stuart, Warren J. Scott, Earle Devendorf, Francis H. Kingsbury, Gordon M. Fair, E. T. Cranch and Samuel M. Ellsworth participated in the discussion.

A paper, "Waterborne Disease in New York," was read by Earle Devendorf, Assistant Director, Division of Sanitation, New York State Department of Health. William F. Sullivan, Francis H. Kingsbury, Warren J. Scott, E. Sherman Chase and C.-E. A. Winslow took part in the discussion.

A paper, "Advances in Iron Coagulation and Coagulants," was read by E. L. Bean, Chemist, Department of Public Works, Providence, R. I. L. H. Enslow and J. J. Healy discussed the paper.

An illustrated paper, "Determination of Odors and Tastes in Water," was read by Professor Gordon M. Fair, Harvard University, Cambridge, Mass. L. H. Enslow, E. Sherman Chase, C.-E. A. Winslow, E. L. Bean and Gilbert H. Pratt took part in the discussion.

The President read the Report of the Finance Committee. (See p. 333.) This report was accepted.

Secretary Gifford announced the election by the Executive Committee of the following new members: Paul D. Mallay, Chief Engineer, Transit Department, Johns-Manville Corporation, New York, N. Y.; Frank S. Brainard, Division Engineer, Hartford Metropolitan District Water Bureau, Hartford, Conn.; Warren A. Gentner, Office Engineer, Hartford Metropolitan District Water Bureau, Hartford, Conn.; Mark F. Croker, Superintendent, Source of Supply, Newton Water Department, Newton, Mass.; Harrison E. Miles, Superintendent, Seymour, Conn.; Arthur Amosa Woodford, President, Avon Water Company (retired), Avon, Conn.

Associates: Cambridge Machine and Tool Company, 150 Medford St., Somerville, Mass.; Roy S. Barker, 619 Chestnut St., Springfield, Mass.; Baldwin-Southwark Corporation, Philadelphia, Pa.; Jenkins Bros. (reinstated), 510 Main St., Bridgeport, Conn.

Afternoon Session.

SUPERINTENDENTS' SESSION ON MANAGEMENT.

A paper, "Group Management of Water Companies," was read by Reeves J. Newsom, President, Community Water Service Company.

A paper, "Municipal Management," was read by Leland G. Carleton, Registrar, Springfield Municipal Water Works, Springfield, Mass.

The subject of management of water companies and municipal plants was discussed by Frank J. Gifford, David A. Heffernan, Theodore L. Bristol, W. C. Hawley, Carleton E. Davis, Hugh McLean, Henry T. Gidley, William A. MacKenzie, Rupert W. Wigmore, E. T. Cranch, Samuel H. MacKenzie, L. H. Enslow, Harold W. Griswold, William B. Duffy and Roger W. Esty.

Mr. David A. Heffernan opened a discussion on the best methods of cutting lined pipe. Reeves J. Newsom, Percy S. Wilson, Joseph H. Hoy, Roger W. Esty, Percy R. Sanders and W. R. Conard took part in this discussion.

Mr. Percy R. Sanders brought up the subject of fineness of screens on gravity supplies. Percy S. Wilson and President Ellis made remarks on this topic.

In the evening a smoker was enjoyed by the members and their guests through the courtesy of the Water Works Manufacturers Association.

FRIDAY, SEPTEMBER 22.

Morning Session.

This Session was devoted to a discussion of the National Recovery Act, Public Works Plan. The following speakers were heard: E. Sherman Chase, reporting on behalf of the NEW ENGLAND WATER WORKS ASSOCIATION Recovery Committee; A. L. Hoffman, State Engineer for Connecticut and Rhode Island under the N R A; Gerald W. Knight, W. J. Scott, W. A. Gentner, E. Sherman Chase and President Ellis took part in the discussion.

Report of Tellers of Election.

The Tellers of Election submitted the following report:

Total Ballots Cast	188
Blank	3

President.

Term Expiring September, 1934

E. Sherman Chase	184
Blank	1

Vice-President.

Term Expiring September, 1935

Roger W. Esty	181
Blank	4

Director.

Term Expiring September, 1936

George A. Sampson	182
Blank	3

Treasurer.

Term Expiring September, 1934

Albert L. Sawyer	182
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(*Signed*) Arthur C. King, *Chairman.*
William B. Duffy,
Charles J. Crump.

Vote of Thanks.

Warren J. Scott. Mr. President, I have a resolution I should like to present:

Resolved: That the thanks of the Association be extended to his Honor the Mayor, the Chamber of Commerce, the Bridgeport Hydraulic Company and the Water Works Manufacturers Association for the many courtesies they have shown the Association, and for their assistance in making the Fifty-second Annual Convention so enjoyable and successful.

(The resolve was duly seconded and unanimously carried.)

Presidential Address by Retiring President Richard H. Ellis.

The New England Water Works Association during its Fifty-second year has passed through a critical economic time with practically no loss of membership, and financially with much less proportional loss than has been experienced by most of the individual members. The shrinkage in income — that of 1932–33 being less than that of the preceding year by 12 per cent.— was practically offset by a 15 per cent. reduction in expenditures. The Association throughout the year operated at a profit which permitted transferring to the Invested Fund the sum of $1 272.28, bringing the Invested Fund to the creditable figure of $17 702.37 and leaving as a cash balance, not included in the invested funds, the sum of $1 955.99.

Reflection on the condition of the Association's finances would indicate that this permanent fund has in the last eight years increased by something like $9 000, an average of better than $1 000 per annum. During this period the Association without raising its dues, experienced all the disadvantages of a high market and similarly with a surprisingly small loss has recently passed through a period in which the income of practically all of the members has been curtailed to a point which is somewhat reflected in our decreased receipts.

If the Association is able to sail successfully over calm and rough seas maintaining a comparatively even keel and is able through all to accumulate funds at the rate of approximately $1 000 per year, there can be little doubt as to its firm financial standing.

This discussion of finances leads to one thought. With the Invested Fund amounting to $17 702.37 and with a cash account of $1 955.99, a large portion of which I believe could safely be transferred to the invested account, the Association is opening its fifty-third year with a cash surplus of nearly $20 000. To what purpose could this Invested Fund be justifiably applied and what limit, if any, should be placed thereon?

At present the income from the Invested Fund is reported as an annual receipt, which as the Fund grows will increase proportionately. The fund is not self-expanding but is dependent wholly on the transfer to it of unexpended balances.

The cash surplus of the Association has apparently been accumulated with no purpose in view other than to establish a sound financial reserve, and your President would in no way wish to convey the opinion that he felt that any material change in this policy is warranted. It is your President's opinion that the present fund should not be reduced except to meet unexpected contingencies such as the establishment of new headquarters, when the time warrants, and that the fund should be further developed by diverting to it surplus cash on hand.

It does, however, seem that the accumulation of surplus has now reached the point where it would be safe and probably desirable to divert

the return from it to some specific purpose in keeping with the objects of the Association, *i. e.*, "the advancement of knowledge relating to water works and water supply, and the encouragement of professional and social intercourse among water-works men."

Your President is not going to urge upon you any definite use of this income from investments, but does at this time desire to make the suggestion that some study be given to the disposition of this money in such a way that the Association will receive, either by way of increased membership, increased interest in the preparation of worthwhile papers, more intensified interest in the water works school, or in some other way a direct return from such an investment.

Merely as a guide for any committee, the Association might at some future time appoint to consider the merit of such action as has been herein proposed, your retiring President would like to suggest that the Water-Works School, as sponsored by the Association, could be materially expanded by the use of such moneys so as to prove of greater benefit to the membership.

Another thought is that in order to provide an incentive for the preparation of more high-calibre papers an exchange of speakers might be arranged with the Institute of Water Engineers of Great Britain whereby the author of the paper considered the most meritorious, or the most representative of some feature of American practice within a period of two years, could be sent every other year at the Association's expense (limited of course to a definite figure) to represent the NEW ENGLAND WATER WORKS ASSOCIATION at one of the British Institute meetings.

Possibly the one topic that has for the last two or three years been pre-eminent in the minds of us all has been that of unemployment. It is true, I believe, that the Association's members have, of themselves, been fortunate in the security of their positions, for there has been little or no unemployment among our active membership. Our employees, however, as we all well know, have not as a rule shared this security, and almost every water-works official has been attempting, with the scant funds available, to have his department do its utmost to relieve unemployment.

We know of the efforts of many of our members in anticipating the needs of their communities and of their construction of reservoirs, pipe lines, dams and other works with men not familiar with construction work. These efforts, while sincere and not to be in any way belittled, have in a broad sense availed little, due to the fact that they have been localized, and as a rule short-lived.

We are today on the threshold of a new gigantic experiment, one of proportions which exceed our wildest fancies of a short time ago. It is a most logical experiment and one which could be carried out by none other than the Federal Government.

Today we should not be handicapped, if our projects are worthy, by scarcity of funds. The Government by its offer to share with us our ex-

penditures, has in effect lowered the already low cost of securing permanent construction for those who are ready to accept at once the opportunities at hand. The employment that should result from the Government Public Works Plan, not being confined to any particular location, will relieve the municipal welfare departments of the tremendous burdens of the past, and should turn into permanent assets the funds hitherto spent either as partial or full doles. Provided that those of us in a position so to do give wholehearted coöperation to the government in this experiment the supply and business organizations will react to revived business. The desk man can return to his desk, the machinist to his lathe, the textile worker to his loom, leaving the tasks of labor to the laborer, and the experiences of the recent past will, we trust, become history.

Are we, however, at the end of the Depression? Are we, if entering a period of revived business activities, going to so submerge ourselves in the new tasks ahead that we shall be forgetful of recent happenings?

Unless as a result of having passed through this period of economic chaos some definite steps are now taken to forestall a similar occurrence in the future, we as a nation will indeed have been short sighted. For "There is some sort of good in things evil, Would men observingly distil it out."

Let us therefore distil from our recent experiences, while they are yet fresh in our minds, some safeguards to prevent us from again falling into the pitfall of misery — unemployment. It is not inconceivable that the creation by industry in general, and in particular by the Federal, State and Municipal governments, of reserve funds to be expended for projects requiring a high percentage of labor, only upon the lowering of the labor index to a predetermined level and then only in such proportion as to properly balance the index, would materially stabilize employment.

Our most earnest effort should be turned to the eradication of the spectre "Unemployment."

(*Adjourned.*)

Annual Report of the Secretary.

Mr. President and Gentlemen of the New England Water Works Association,— The Secretary submits herewith the following report of the changes in membership during the past fiscal year, and the general condition of the Association.

The present membership is 800, constituted as follows: 11 Honorary Members, 679 Members, 0 Juniors, 15 Corporate Members and 95 Associate Members. The detailed changes are as follows:

MEMBERSHIP.

September 1, 1932.	Honorary Members	14			
	Withdrawals:				
	Died	3			11
September 1, 1932.	Members, Total		683		
	Withdrawals:				
	Resigned	17			
	Died	11	28	655	
	Elected:				
	September, 1932	9			
	November, 1932	1			
	December, 1932	2			
	January, 1933	2			
	February, 1933	2			
	March, 1933	1			
	April, 1933	6			
	June, 1933	1		24	679
September 1, 1932.	Juniors, Total		0		
September 1, 1933.	Juniors, Total		0		0
September 1, 1932.	Associates, Total		97		
	Withdrawals:				
	Resigned		2		95
September 1, 1932.	Corporate Members, Total		15		
September 1, 1933.	Corporate Members, Total		15		15
September 1, 1933.	Total Membership				800
September 1, 1932.	Total Membership				809
	Net Loss				9

Elections.

Members.

September 28, 1932. Theodore M. Beach, Harold L. Brigham, Chester M. Everett, Henry Ibbotson, Jr., Charles E. Miller, Leo. T. Purcell, Fred J. Reny, Daniel C. Smith, Donald Sorelle. (9)
November 9, 1932. Roger G. Oakman. (1)
December 14, 1932. James B. Swaim, John S. Wise. (2)
January 11, 1933. Truman M. Curry, Jr., Clarence I. Sterling, Jr. (2)
February 6, 1933. Samuel M. Ellsworth, Francis W. Hamilton. (2)
March 6, 1933. Percy A. Shaw. (1)
April 26, 1933. Frank J. Callahan, Walter J. Connor, Thomas J. Fleming, Harry F. Martin, J. William Nolan, Marshall S. Wellington. (6)
June 20, 1933. William D. Paine. (1)

Resignations and Deaths.

Members.

Resigned: J. A. Amyot, H. W. Baker, A. W. P. Cobb, S. E. Coburn, W. S. Cramer, F. J. Dixon, C. E. Gardner, C. B. Garmon, F. A. Gay, F. W. Green, F. T. Look, G. A. Johnson, W. A. Kennedy, J. S. Langthorn, A. B. Morrill, A. G. Nolte, F. W. Young. (17)
Died: C. S. Denman, I. G. Hoagland, H. C. Kerr, Morris Knowles, F. T. Lamey, J. W. Ledoux, John P. Lucy, J. R. McClincock, E. D. Pingree, C. W. Shippee, J. P. Wood. (11)

Associates.

Resigned: F. A. Houdlette & Son and The Pratt & Cady Company. (2)

Receipts for the Fiscal Year, September 1, 1932 to September 1, 1933.

Entrance Fees			$72.00
Annual Dues:			
Members	$3 464.03		
Corporates	150.00		
Associates	1 620.00	$5 234.03	
Fractional Dues:			
Members	48.00	48.00	
Past Dues:			
Members	69.00	69.00	
1933–1934 Dues:			
Members	13.00		
Associates	20.00	33.00	

Total Dues		5 384.03
Advertisements		3 049.00
Subscriptions		355.00
JOURNALS		52.00
Sundries		1 078.51
Total Receipts		$9 990.54
There is due the Association:		
Advertisements	$676.00	
Subscriptions	140.00	
JOURNALS	2.50	
Reprints	6.10	
Standard Specifications	.75	
Electro	4.75	
Half-tone	4.90	835.00
Total		$10 825.54

Respectfully submitted,

FRANK J. GIFFORD, *Secretary.*

Annual Report of the Treasurer.

September 1, 1932 to August 31, 1933.

The President and Members of the New England Water Works Association:

I herewith submit my report as Treasurer for the year ending August 31, 1933.

Receipts.

September 1, 1932 — Cash on hand			$2 716.54
Initiation fees	$72.00		
Dues	5 384.03	$5 456.03	
Interest and dividends		622.66	
Journal:			
Advertisements	$3 049.00		
Subscriptions	355.00		
Sale of Journals	52.00		
Sale of Reprints	60.90		
Sale of Half-tones	18.49	$3 535.39	
Miscellaneous:			
Certificates of membership	$19.50		
Standard Specifications	.50		
Meter sheets	.05		
B. S. C. E. account June Outing	39.25		
Tuition fees — Water Works School	315.00		
Refund on exchange	.79		
Express	1.37	376.46	
			9 990.54
Total receipts			$12 707.08

Expenditures.

Journal:		
Advertising agent's salary and commission	$104.80	
Editor's salary	500.00	
Editor's expense	34.95	
Plates	358.22	
Printing	2 788.44	
Reporting	370.13	
Reprints	474.21	
Stationery and postage	71.23	
Sundries	10.18	$4 712.16

Amount brought forward		$4 712.16	
Office:			
Certificates of membership	$12.25		
Engineering Societies of Boston	2 117.50		
Exchange and U.S. Tax	8.43		
Printing, stationery and postage	110.48		
Secretary's salary	400.00		
Secretary's expense	154.07		
Treasurer's salary bond and expense	120.55		
Sundries	41.13	2 964.41	
Meetings and Committees:			
Badges	$27.00		
Committee on pipe, share of expense	400.00		
Dinners for guests	9.00		
Printing, stationery and postage	659.81		
Stereopticon	61.00		
Sundries	79.18		
Water Works School	566.25	1 802.24	
Total			$ 9 478.81
Transfer to invested funds			1 272.28
Total expenditures			$10 751.09
August 31, 1933 — Cash on hand			1 955.99
			$12 707.08

Invested Funds.

Invested Funds, September 1, 1932	$15 807.43
Transferred to Invested Funds	1 272.28
Interest on Deposits	24.30
Interest on Savings Bank Deposits	598.36
	$17 702.37
Interest paid over to the Association	$622.66
Invested Funds, August 31, 1933	17 079.71
	$17 702.37

TREASURER'S REPORT.

STATEMENT OF RECEIPTS AND EXPENDITURES.

Receipts.	
Cash on hand September 1, 1932	$2 716.54
Interest on deposits	622.66
Received from Secretary	9 367.88
	$12 707.08

Expenditures.	
Bills paid as per vouchers	$9 478.81
Transferred to Invested Funds	1 272.28
Cash on hand August 31, 1933	1 955.99
	$12 707.08

ASSETS AND LIABILITIES.

Assets.		
Cash in bank as per list		$19 035.70
First National Bank	$1 955.99	
City Five Cents Savings Bank	2 000.00	
Farmers and Mechanics Savings Bank	2 068.46	
Franklin Savings Bank	2 000.00	
Haverhill Savings Bank	2 000.00	
Home Savings Bank	1 011.25	
Mechanics Savings Bank	2 000.00	
Pentucket Savings Bank	2 000.00	
Peoples Savings Bank	2 000.00	
Suffolk Savings Bank	2 000.00	
Accounts Receivable		835.00
Advertisements	676.00	
JOURNALS	2.50	
Subscriptions	140.00	
Reprints	6.10	
Standard Specifications	.75	
Half-tones	9.65	
		$19 870.70

Liabilities.	
Surplus	$19 870.70
	$19 870.70

The Finance Committee for the year ending August 31, 1933, recommended a budget of $11 800.00.

There has been expended $9 478.81, leaving an unexpended balance of $2 321.19. The details are as follows:

	Journals.	Offices.	Meetings.
Appropriation	$6 500.00	$3 200.00	$2 100.00
Expended	4 712.16	2 964.41	1 802.24
Balance	$1 787.84	$235.59	$297.76

The amount received for tuition fees to the Water Works School was $315.00 the same as last year; the expenses were $566.25 making the net cost to the Association $251.25.

By vote of the Executive Committee, the Treasurer transferred the sum of $1 272.28 to the Invested Fund account. This amount was deposited in Savings Banks.

Respectfully submitted,

Albert L. Sawyer, *Treasurer.*

The above report has been examined and certified by Louis Kremer, Certified Public Accountant, and his report, dated September 6, 1933, is on file in the office of the Secretary of this Association.

Annual Report of the Editor.

To the New England Water Works Association: The Editor submits herewith the following report for the year ending August 31, 1933.

As has been customary in the past, the tables of financial figures, accompanying the report, are based upon total charges and accounts receivable, rather than actual cash received or disbursed.

Table 1 is a statement of the material published.

Table 2 gives the receipts and expenditures for the year.

Table 3 is a comparison of the Journal for the past year with preceding years.

Size. The four issues contained 594 pages, of which 420 were text.

Cost. The gross cost of the Journal was $4 112.16, equivalent to $5.85 per member, and the net cost was $1 176.77, equivalent to $1.46 per member.

Reprints. Fifty reprints of each paper have been furnished to the author where desired.

Circulation. The present circulation of the Journal is:

Members, all grades	800
Subscribers	114
Exchanges	16
Total	930

(Journals *have been sent to all subscribers.*)

Respectfully submitted,

Gordon M. Fair, *Editor.*

EDITOR'S REPORT.

TABLE 1.

Statement of Material in September and December, 1932, and March and June, 1933, Issues of the Journal of the New England Water Works Association.

Date.	Pages of.								
	Papers.	Proceedings.	Total Text.	Index.	Advertisements.	Cover and Contents.	Insert Plates.	Total.	Total Cuts.
September, 1932	88	6	94	0	37	5	0	136	33
December, 1932	83	30	113	8	37	5	0	163	22
March, 1933	96	7	103	0	36	5	0	144	26
June, 1933	106	4	110	0	36	5	0	151	18
Total	373	47	420	8	146	20	0	594	99

TABLE 2.

RECEIPTS AND EXPENDITURES ON ACCOUNT OF SEPTEMBER AND DECEMBER, 1932, AND MARCH AND JUNE, 1933, ISSUES OF THE JOURNAL OF THE NEW ENGLAND WATER WORKS ASSOCIATION.

Receipts.		*Expenditures.*	
Advertisements	$3 049.00	Advertising Agent's salary and commission	$104.80
Sale of JOURNALS	52.00	Editor's salary	500.00
Sale of reprints	60.90	Editor's expense	34.95
Subscriptions	355.00	Plates	358.22
Sale of cuts	18.49	Printing	2 788.44
	$3 535.39	Reporting	380.13
		Reprints	474.21
		Stationery and postage	71.23
Net cost of JOURNAL	1 176.77	Sundries	10.18
	$4 712.16		$4 712.16

EDITOR'S REPORT.

TABLE 3.

COMPARISON OF JOURNALS OF THE NEW ENGLAND WATER WORKS ASSOCIATION.

	FOUR ISSUES FOR FISCAL YEAR ENDING AUG. 31,									
	1924.	1925.	1926.	1927.	1928.	1929.	1930.	1931.*	1932.	1933.
Average edition (copies printed)	1 100	1 100	1 100	1 100	1 138	1 200	1 350	1 260	1 200	1 125
Average membership	764	755	775	784	808	831	822	816	813	805
Circulation at end of year	880	873	906	916	955	993	980	955	957	930
Pages of text	404	421	523	492	528	507	570	410	437	420
Pages of text per 1 000 members	529	558	675	628	654	610	693	502	537	522
Total pages, all kinds	611	644	761	724	769	745	812	682	644	594
Total pages per 1 000 members	800	853	982	952	952	896	988	836	790	738
GROSS COST:										
Total	$4 783.60	$5 272.91	$6 524.62	$5 839.36	$6 849.44	$6 740.87	$8 054.59	$6 135.33	$5 024.03	$4 712.16
Per page	7.83	8.19	8.57	8.07	8.91	9.06	9.92	9.00	7.80	7.93
Per member	6.26	6.98	8.42	7.45	8.48	8.12	9.80	7.52	6.18	5.85
Per member per 1 000 pages	10.25	10.84	11.07	10.29	11.02	9.77	12.07	9.00	9.62	9.85
Per member per 1 000 pages text	15.50	16.58	16.10	15.13	16.06	16.01	17.19	18.34	14.30	13.94
NET COST:										
Total	$561.51	$943.40	$2 040.28	$710.63	$1 716.25	$1 857.58	$3 664.76	$1 252.21	$1 121.20	$1 176.77
Per page	0.92	1.46	2.68	.98	2.23	2.07	4.51	1.84	1.74	1.98
Per member	0.74	1.25	2.64	.91	2.12	2.24	4.46	1.53	1.38	1.46
Per member per 1 000 pages	1.20	1.94	3.47	1.26	2.76	2.50	5.49	2.24	2.14	2.46
Per member per 1 000 pages text	1.82	2.97	5.05	1.85	4.02	4.41	7.82	3.73	3.16	3.48

*Including Comprehensive Index, 1882 to 1930.

REPORT OF THE FINANCE COMMITTEE.

To the Executive Committee of the New England Water Works Association:
Gentlemen:

The Finance Committee with the authority of the Executive Committee have this year had an audit of the books made by a certified public accountant. His report is herewith submitted. We recommend the continuing of this practice.

The Committee submits the following budget for the fiscal year ending August 31, 1934:

	Expended. 1932–1933.	Recommended. 1933–1934.
JOURNAL	$4 712.16	$6 300.00
Office	2 964.41	3 300.00
Meetings and Committees	1 802.24	2 200.00
	$9 478.81	$11 800.00

The total amount recommended is well within a conservative estimate of receipts for the coming year. We feel that the additional allowance over expenditures for the past year will be needed on account of the upward trend of prices due to the N R A.

Respectfully submitted,

(Signed) STEPHEN H. TAYLOR,
S. ALFRED BENSON,
R. W. MACDONALD.
Finance Committee.

September 14, 1933.

WALTER H. RICHARDS.

Walter H. Richards, a member of this Association for fifty-one years and an Honorary Member since 1920, died at his home in New London, Connecticut, in the early morning of February 17, 1933. He was born in New London on May 12, 1852 and was educated in the schools of his native city. Early in life he chose the profession of Civil Engineering and must have evidenced more than usual ability for in 1871, when scarcely twenty years of age, he became Assistant to J. T. Fanning who designed and built the New London Water Works. Much of the preliminary work, both in surveys and detail plans, for the construction fell to Mr. Richards' lot. He also became Resident Engineer in charge of construction. These were the days of "cement coated stove pipe" when eternal vigilance was the price paid for tight joints and substantial work. The many years that this type of pipe remained in the streets of New London with a minimum of expense for repairs testify to careful and painstaking supervision during construction.

On completion of the New London Water Works Mr. Richards was made Superintendent and Engineer of the Water Department and the supervision of this department together with the Sewer Department organized a few years later became his life interest. In 1886, with Rudolph Hering of New York as Consulting Engineer, Mr. Richards designed and built the New London Sewer system and continued as Engineer for the Sewer Department which for a number of years was entirely separate from the Water Department. The two departments were eventually combined under one Board of Water and Sewer Commissioners.

In New London as in every growing community the demands on the water department steadily increased; more water was needed for both domestic and industrial purposes; better fire service was imperative as was also higher pressure on the hill tops. During Mr. Richards' years of service the plant was practically rebuilt; new supply and distribution pipes were laid; a new reservoir nearly doubling the storage capacity was built; and much modern equipment was added. When he retired in 1921 he was able to turn over, to his successor in office, works that were a credit to both himself and his city.

Besides being an enthusiastic member of the New England Water Works Association Mr. Richards was a member of the Connecticut Society of Civil Engineers and of Brainard Lodge A. F. and A. M. of New London.

After his retirement in 1921, which came when the city-manager form

of government was adopted in New London, either from choice or because of failing health, Mr. Richards led a very secluded life, taking no part in public activities and rarely being seen on the street.

His was the rather unusual record of having spent all his years of active service, from boyhood to the time of his retirement, in one department in his native city.

L. E. Daboll
Byron I. Cook.